

DESCRIPTION

TITLE

CONVEYANCE ASSISTANCE 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.

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[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]

When the configuration described in Patent Document 1 is adopted to assist the movement of a target such as a chassis, commanded rotational speeds of the motors can be set to follow the movement.

[0006]

10 However, when the motors simply follow the movement of the target, a transporter handling the target does not have a “feeling of being assisted,” and the transporter feels that the bed is heavy to push. Further improvement is required to make the target easy to push.

[0007]

The present disclosure has been made in view of the above circumstances, and an
15 object thereof is to make a target easy to push by assisting the movement of the target.

SOLUTION TO THE PROBLEM

[0008]

A first aspect of the present disclosure relates to a transport assistance apparatus for
20 assisting a movement of a target made by an external force. The transport assistance apparatus includes: a wheel attached to the target; a motor connected to the wheel to drive the driving wheel; a current sensor that detects an induced current flowing through the motor when the wheel rotates; and a controller that controls the motor. The controller estimates an acceleration of the target based on a detection signal of the current sensor, performs first control of
25 commanding a rotational speed of the motor based on the acceleration to follow the movement

of the target, and performs second control of increasing the commanded rotational speed set in the first control when it is determined that an absolute value of the acceleration is equal to or greater than a predetermined value.

[0009]

5 According to the first aspect, detecting the induced current allows estimating torque that causes the induced current (the torque that causes the wheel to rotate). Estimating the torque allows estimating the acceleration of the target. The acceleration increases according to the external force applied by the operator. Thus, whether the target is pushed or not can be determined by determining whether the absolute value of the acceleration is equal to or greater
10 than the predetermined value.

[0010]

 Performing the second control in addition to the first control not only allows the motor to simply follow the target, but also reduces load on a transporter by the amount of increase in the commanded rotational speed. This makes it easier to push the target, and can give the
15 transporter an appropriate “feeling of being assisted.”

[0011]

 By performing the second control when the absolute value of the acceleration is equal to or greater than the predetermined value, that is, when the target is pushed, the timing when the transporter pushes the target and the timing when the target becomes easy to push can be
20 synchronized. This can give the transporter an adequate feeling of being assisted. The transport assistance apparatus is configured to perform the second control on condition that the target is pushed. This can avoid a situation in which the transport assistance apparatus unintentionally travels as a result of the second control performed when the target is not pushed.

[0012]

25 According to a second aspect of the present disclosure, the transport assistance

apparatus may include a rotation sensor that detects a rotational speed of the motor, and when increasing the commanded rotational speed, the controller may increase the commanded rotational speed as the rotational speed detected by the rotation sensor increases.

[0013]

5 It is considered that the detected value of the rotational speed increases as the transporter pushes the target harder. According to the second aspect, the more strongly the target is pushed by the transporter, the stronger thrust assists the movement of the target. This can provide assistance according to the magnitude of the external force, and advantageously makes the target easy to push.

10 [0014]

 According to a third aspect of the present disclosure, the controller reduces the commanded rotational speed after the second control when the absolute value of the acceleration falls below the predetermined value.

[0015]

15 According to the third aspect, when the transporter gently pushes the target or takes the hand off the target, the movement of the target is assisted with a weaker thrust. This can provide assistance according to the magnitude of the external force, give the transporter an adequate feeling of being assisted, and keep the transport assistance apparatus from unintentionally travelling by itself.

20 [0016]

 According to a fourth aspect of the present disclosure, the transport assistance apparatus may include a rotation sensor that detects a rotation speed of the motor, and the controller may permit driving of the wheel on condition that the rotational speed is equal to or greater than a predetermined value based on a detection signal of the rotation sensor.

25 [0017]

According to the fourth aspect, the driving of the wheel is restricted when the rotational speed is less than the predetermined value. This allows the first control and the second control to be performed only when the target is actually being transported. This contributes to improvement in usability of the transport assistance apparatus.

5 [0018]

According to a fifth aspect of the present disclosure, the transport assistance apparatus may include a rotation sensor that detects a rotational speed of the wheel; and an inclination sensor that detects an inclination angle of a transport surface on which the target travels. The controller may determine whether the transport surface is a slope based on a detection signal of the inclination sensor. When it is determined that the transport surface is not the slope, the controller may perform both the first control and the second control based on the acceleration obtained by the current sensor. When it is determined that the transport surface is the slope, the controller may determine whether the target is ascending the slope based on the detection signals of the rotation sensor and the inclination sensor. When it is determined that the target is ascending the slope, the controller may increase the acceleration obtained by the current sensor and perform the first control based on the increased acceleration without performing the second control.

[0019]

When the second control is performed while the target is ascending the slope, the transporter may feel more assisted only when the transporter starts to push the target, but the feeling does not increase after the start (during uphill travel). Thus, according to the fifth aspect, when it is determined that the vehicle is ascending the slope, the acceleration referred to for the first control is increased, and the first control is performed based on the increased acceleration. Increasing the acceleration is equivalent to estimating the external force acting on the target to be larger than the external force actually acting. By estimating the external force to be large,

assistance is given to exert a thrust stronger than a thrust to follow the movement of the bed. This process is performed as long as the uphill travel continues, and can continuously provide a good assist feeling while the bed is ascending the slope.

[0020]

5 According to a sixth aspect of the present disclosure, the transport assistance apparatus may include a rotation sensor that detects a rotational speed of the wheel; and an inclination sensor that detects an inclination angle of a transport surface on which the target travels. The controller may determine whether the transport surface is a slope based on a detection signal of the inclination sensor. When it is determined that the transport surface is not the slope, the
10 controller may perform both the first control and the second control based on the acceleration obtained by the current sensor. When it is determined that the transport surface is the slope, the controller may determine whether the target is descending the slope based on the detection signals of the rotation sensor and the inclination sensor. When it is determined that the target is descending the slope, the controller may perform the first control based on the acceleration
15 obtained by the current sensor without performing the second control.

[0021]

 If the second control is performed while the target is descending the slope, the target may be accelerated more than necessary and separated from the hand of the transporter. Thus, according to the sixth aspect, when it is determined that the target is descending the slope, the
20 first control alone is performed without increasing the acceleration and without performing the second control. This can give the transporter an appropriate feeling of being assisted while descending the slope.

[0022]

 According to a seventh aspect of the present disclosure, for the first control, the
25 controller may maintain a value of the commanded rotational speed when the commanded

rotational speed is less than a predetermined threshold, and may change the commanded rotational speed to the threshold when the commanded rotational speed is equal to or greater than the threshold.

[0023]

5 According to the seventh aspect, the value of the commanded rotational speed can be maintained at the threshold or less. This improves the safety of the transport assistance apparatus more than before.

[0024]

 According to an eighth aspect of the present disclosure, the target may be a bed with
10 casters, and the wheel may be attached to a lower portion of the bed with casters.

[0025]

 According to the eighth aspect, the target is a bed with casters. The transport assistance apparatus can also provide assistance in moving a heavy object such as the bed with casters, and the transporter can feel that the bed is easy to push.

15

ADVANTAGES OF THE INVENTION

[0026]

 As described above, the present disclosure makes it easy for a transporter to push a target by assisting the movement of the target.

20

BRIEF DESCRIPTION OF THE DRAWINGS

[0027]

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

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 [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 a configuration of the transport assistance apparatus.

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

[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.

[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.

[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.

[FIG. 16] FIG. 16 is a flowchart of a process related to ascending/descending a slope.

[FIG. 17] FIG. 17 is a flowchart illustrating safety limit control.

DESCRIPTION OF EMBODIMENTS

[0028]

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

[0029]

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
10 configuration of the transport assistance apparatus 1 and the caster bed 10.

[0030]

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

[0031]

15 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.

[0032]

20 The transport assistance apparatus 1 is attached to a given target. The transport assistance apparatus 1 assists a movement of the target made by an external force (e.g., an external force applied by a transporter 100).

[0033]

As shown in FIGS. 1 and 2, the target according to the present embodiment is a bed 10
25 with casters (hereinafter simply referred to as a “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.

[0034]

Hereinafter, a lengthwise direction of the bed 10, that is, a direction in which a person 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.”

[0035]

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 (a floor surface on which the bed 10 travels) F.

[0036]

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.

[0037]

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.

[0038]

The bed body 11 includes a headboard 11h arranged at a rear end of the bed 10, a
5 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.

[0039]

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
10 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.

[0040]

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

[0041]

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
20 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.

[0042]

As shown in FIGS. 1 and 2, the front casters 14F and the rear casters 14B constituting
25 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.

[0043]

5 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
10 fork 14b swivels relative to the mount 14a.

[0044]

 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
15 the rear casters 14B in the front-rear direction and at the center of the bed 10 in the left-right direction.

[0045]

 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 as wheels, first and second motors
20 22R and 22L, a controller 4, first and second current sensors SW1 and SW2 serving as current sensors, first and second rotation sensors SW3 and SW4 serving as rotation sensors, and a six-axis sensor SW5 as an inclination 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
25 second mecanum wheel 21L is located on the left.

[0046]

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.

[0047]

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.

10 [0048]

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.

[0049]

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.

[0050]

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.

[0051]

5 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.

[0052]

10 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.

[0053]

 The second arm member 72L on the left side in FIGS. 3 and 4 is swingably supported
15 by the rear rail member 71b, similarly to the first arm member 72R. 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.

[0054]

20 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).

[0055]

 As shown in FIGS. 1 and 2, the first and second mecanum wheels 21R and 21L are
25 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 the left-right direction which is the widthwise direction, as shown in FIG. 2.

[0056]

Specifically, as shown in FIGS. 3 to 5, the first mecanum 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.

[0057]

The second mecanum 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.

[0058]

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.

[0059]

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.

[0060]

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.

[0061]

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.

[0062]

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.

[0063]

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.

[0064]

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.

[0065]

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.

[0066]

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.

[0067]

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.

[0068]

Specifically, the first current sensor SW1 detects an induced current flowing through
25 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.

[0069]

5 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 the external force. The magnitude of the torque is associated with the magnitude of the external force applied to the bed 10, and thus, to 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
10 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.

[0070]

 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
15 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.

[0071]

 The magnitude of the induced current is proportional to the torque acting on the second
20 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, to 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
25 to the motor current that flows when the second motor 22L is driven.

[0072]

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 22L rotates forward.

[0073]

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 specifically, by rotating the first and second motors 22R and 22L at the commanded rotational speeds corresponding to the torque).

[0074]

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 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.

[0075]

As shown in FIG. 8, the six-axis sensor SW5 as the inclination sensor detects an inclination angle of the transport surface F on which the bed 10 travels. Specifically, the six-axis sensor SW5 is configured to be able to detect at least an angular velocity of a rotation angle about a y-axis extending in the left-right direction (so-called pitch angle θ).

[0076]

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

[0077]

10 The controller 4 controls the first and second motors 22R and 22L based on the 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.

[0078]

More specifically, the controller 4 commands the rotational speeds of the first and
15 second motors 22R and 22L based on the detection signals inputted from the sensors SW1 to 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.

[0079]

20 The first mecanum wheel 21R rotates at the same rotational speed as the first motor 22R, and the second mecanum wheel 21L rotates at the same rotational speed as the second motor 22L. That is, setting the commanded rotational speeds of the first and second motors 22R and 22L is equivalent to setting the commanded rotational speeds of the first and second mecanum wheels 21R and 21L.

25 [0080]

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.

5 [0081]

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
10 the bed 10 obliquely forward to the right (see an arrow A_{12} in FIG. 7).

[0082]

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
15 transport assistance apparatus 1 to generate a thrust to the front. This thrust can assist the bed 10 to move forward.

[0083]

Similarly, when the first mecanum wheel 21R located on the right rotates rearward, a
20 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 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).

[0084]

25 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.

[0085]

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.

10 [0086]

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.

[0087]

15 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.

[0088]

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).

[0089]

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

25

second motors 22R and 22L based on the detection signals of the sensors SW1 to SW5.

[0090]

To provide 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.

[0091]

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.

[0092]

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.

[0093]

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

[0094]

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.

[0095]

FIG. 16 is a flowchart of a process related to ascending/descending a slope. FIG. 17 is
5 a flowchart illustrating safety limit control.

[0096]

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

[0097]

10 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.

[0098]

Hereinafter, the acceleration of the first mecanum wheel 21R is referred to as a “first
15 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 the translational velocity, that is, so-called tangential accelerations.

[0099]

The magnitude of the induced current detected by each of the first and second current
20 sensors SW1 and SW2 is proportional to 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
25 torque stored in the controller 4 in advance may be used.

[0100]

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.

5 [0101]

To provide 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).

[0102]

10
$$a_r = (-1) \cdot T_r / (R \cdot m) \cdots (1)$$

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

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.

15 [0103]

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.

20 [0104]

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.

[0105]

25 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 using the first and second accelerations a_r and a_l estimated based on the detection signals of the first and second current sensors SW1 and SW2.

[0106]

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 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.

[0107]

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

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

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 the left and right sides.

[0108]

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).

[0109]

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 first rotation sensor SW3, and the second rotational speed r_l is detected by the second rotation sensor SW4.

[0110]

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 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.

[0111]

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

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

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 .

[0112]

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

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

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.

[0113]

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

[0114]

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

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

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 .

[0115]

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

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

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 the lateral rotational speed r_l can be determined.

[0116]

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 greater than a predetermined value (first threshold) based on the detection signals of the first and second rotation sensors SW3 and SW4.

[0117]

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 determination.

[0118]

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

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

In the expressions (13) and (14), T1 [1/s] is a first threshold. The magnitude of the first 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 .”

[0119]

If both of the expressions (13) and (14) are not satisfied, the controller 4 determines 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.

[0120]

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.

5 [0121]

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
10 (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 .

[0122]

Steps S11 to S16 of FIG. 10 illustrate the process performed in Step S6 of FIG. 9. That
15 is, when the control process proceeds to Step S6, the controller 4 starts Step S11 of FIG. 10.

[0123]

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
20 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 .

[0124]

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

[0125]

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

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
5 necessary.

[0126]

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.

10 [0127]

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).

[0128]

15 In the subsequent Steps S13 and S14, the controller 4 determines whether the transport surface F is a slope based on the detection signal of the six-axis sensor SW5 serving as the inclination sensor.

[0129]

Specifically, in Step S13, the controller 4 calculates the inclination angle (road surface
20 gradient) θ_s of the transport surface F based on the detection signal of the six-axis sensor SW5. This calculation can be performed based on, for example, an angular acceleration about the y-axis shown in FIG. 8.

[0130]

Then, in Step S14, the controller 4 determines whether the following relational
25 expression (16) is satisfied.

[0131]

$$|\theta_s| \geq T3 \cdots (16)$$

In the expression (16), T3 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.

5 [0132]

If the above expression (16) is not satisfied, the controller 4 determines that the transport surface F is a flat road without inclination, and advances the control process to Step S15.

[0133]

10 The process proceeds to Step S15 if it is determined that the bed 10 is moving forward or rearward without ascending or descending the slope. In this case, in order to assist the hand-propelled movement of the bed 10 in the front-rear direction, 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.

[0134]

If the above expression (16) is satisfied, the controller 4 determines that the transport surface F is a slope, and advances the control process to Step S16.

[0135]

20 The process proceeds to Step S16 if it is determined that the bed 10 is moving forward or rearward and ascending or descending the slope. In this case, the controller 4 performs control for assisting the hand-propelled movement of the bed 10 in the front-rear direction, in particular, control optimized for ascending or descending the slope.

[0136]

25 The process performed in Steps S12 and S15 and the process performed in Step S16

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.

[0137]

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 movement of the bed 10 which is the target.

[0138]

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 .

[0139]

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 .

[0140]

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.

[0141]

The velocity increase control is performed by the controller 4 based on the
5 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
10 commands V_x and V_y) set by the compliance control.

[0142]

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
15 particular, the absolute values of the commanded rotational speeds R_r and R_l).

[0143]

First, a case where the control process proceeds to Step S12 or S15 will be described. Here, Steps S31 to S37 shown in FIG. 15 are the processes performed in Step S12 or S15 shown in FIG. 10. That is, when the control process proceeds to Step S12 or S15, the controller 4
20 performs each step in order from Step S31 of FIG. 15.

[0144]

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
25 increase control based on the lateral velocity command V_y obtained by the compliance control.

[0145]

If the process proceeds from Step S15 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. Specifically, “ a_x / a_y ” in Step S31 of FIG. 15 means “either one of a_x or a_y ” rather than “a quotient of a_x by a_y .”

[0146]

Then, a case where the process proceeds from Step S15 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 Steps S32 to S34 are related to the velocity increase control.

[0147]

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 and second current sensors SW1 and SW2, and corresponds to an estimated value (actual measurement) of the longitudinal acceleration a_x .

[0148]

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 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.

[0149]

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 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.

[0150]

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.

[0151]

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.

[0152]

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 .

[0153]

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).

10 [0154]

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 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).

[0155]

20 By reflecting the two types of feedback on the longitudinal acceleration a_x , the 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.

25 [0156]

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.

[0157]

5 For example, as shown in the upper part of FIG. 12, when the transport assistance 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
10 apparatus 1 does not accelerate or decelerate.

[0158]

 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
15 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
20 as the bed 10 and the transporter 100.

[0159]

 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
25 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.

[0160]

In the subsequent Steps S32 to S34, the controller 4 performs the above-described velocity increase control. When the controller 4 performs 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 .

[0161]

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 .

[0162]

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.

[0163]

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 (detection of a pushing force).

[0164]

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

In the expression (17), $T4 [m/s^2]$ is a fourth threshold (predetermined value). The 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.

[0165]

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 determines whether the acceleration in the moving direction determined in Step S11 in FIG. 10 is equal to or greater than the fourth threshold $T4$.

[0166]

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 4 determines that the bed 10 is being pushed, and advances the control process to Step S34 (Step S33: YES).

[0167]

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

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 .

5 [0168]

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.

[0169]

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).

[0170]

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

[0171]

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.

[0172]

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.

[0173]

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).

[0174]

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.

[0175]

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 $t_2 < t < t_3$).

[0176]

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
5 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 rises 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
10 the bed 10.

[0177]

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
15 FIG. 12. In this case, YES is not selected in the determination at Step S33, and the velocity 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.

[0178]

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

[0179]

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
25 description may be replaced with the term “lateral,” and the term “front-rear” with the term

“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 different in the front-rear direction and the left-right direction.

[0180]

5 Then, a case where the process proceeds to Step S16 in FIG. 10 will be described below. In this case, Steps S41 to S44 in FIG. 16 are performed in order.

[0181]

 In Step S41, the controller 4 determines whether the bed 10 is going up or down a slope, that is, whether the bed 10 is ascending the slope, based on the detection signals of the
10 first and second rotation sensors SW3 and SW4 and the six-axis sensor SW5.

[0182]

 In Step S41, YES is selected when the road surface gradient θ_s increases toward the front and the moving direction is the front (the longitudinal rotational speed r_x or the longitudinal velocity $v_x > 0$) or when the road surface gradient θ_s decreases toward the front
15 and the moving direction is the rear (the longitudinal rotational speed r_x or the longitudinal velocity $v_x < 0$).

[0183]

 In Step S41, NO is selected when the road surface gradient θ_s increases toward the front and the moving direction is the rear, or when the road surface gradient θ_s decreases toward
20 the front and the moving direction is the front.

[0184]

 A value calculated in Step S13 can be used as the road surface gradient θ_s referred to in the determination of Step S41.

[0185]

25 When it is determined that the bed 10 is going up the slope (Step S41: YES), the

controller 4 increases the longitudinal acceleration a_x obtained by the first and second current sensors SW1 and SW2, and performs the compliance control based on the increased longitudinal acceleration a_x' without performing the velocity increase control.

[0186]

- 5 Specifically, in Step S42 following Step S41 when the determination of Step S41 is YES, the controller 4 increases the longitudinal acceleration a_x obtained by the first and second current sensors SW1 and SW2. The increase amount Δa_x at that time may be set to increase as the road surface gradient θ_s increases, for example.

[0187]

- 10 In Step S43 following Step S42, the controller 4 performs the compliance control for the front-rear direction based on the increased longitudinal acceleration a_x' . Details of Step S43 are the same as those of Step S31 for the front-rear direction except that the increased longitudinal acceleration a_x' is used.

[0188]

- 15 When it is determined that the bed 10 is going down the slope (Step S41: NO), the controller 4 does not increase the longitudinal acceleration a_x obtained by the first and second current sensors SW1 and SW2, and performs the compliance control based on the longitudinal acceleration a_x without performing the velocity increase control.

[0189]

- 20 Specifically, in Step S45 following Step S41 when the determination of Step S41 is NO, the controller 4 sets the increase amount of the longitudinal acceleration a_x obtained by the first and second current sensors SW1 and SW2 to zero to maintain the value of the longitudinal acceleration a_x .

[0190]

- 25 Then, in Step S43 following Step S45, the controller 4 performs the compliance control

for the front-rear direction based on the longitudinal acceleration a_x' which is not increased ($= a_x$). Details of Step S43 are the same as those of Step S31 described above.

[0191]

Thereafter, in Step S44 following Step S43, the controller 4 determines the final assist
5 velocity in the front-rear direction as in Step S36 described above.

[0192]

When the bed is ascending the slope, the longitudinal acceleration a_x continues to
increase as long as the bed keeps ascending the slope, as shown in Steps S41 and S42 in FIG.
16. On the other hand, as described with reference to FIG. 14, the rise of the assist rotational
10 speed in the velocity increase control is substantially synchronized with the timing when the
longitudinal acceleration a_x reaches or exceeds the predetermined value, that is, the timing
when the external force acts on the bed 10.

[0193]

In other words, the controller 4 according to the present embodiment determines
15 whether the bed is traveling on a flat road or ascending the slope. Based on the determination
result, the controller 4 intermittently increases the commanded rotational speeds of the motors
(the first and second motors 22R and 22L) in synchronization with the application of the
external force when the bed is traveling on the flat road, or keeps the increase of the commanded
rotational speeds when it is determined that the bed is ascending the slope as long as the bed
20 keeps ascending the slope.

[0194]

When the flow of Steps S12, S15, and S16 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
25 commanded rotational speed R_r and the second commanded rotational speed R_l by the following

expressions (18) and (19) determined in the same manner as the above expressions (5) and (6).

[0195]

$$R_r = 60 * (V_x + V_y) / (2\pi \cdot R) \cdot \cdot \cdot (18)$$

$$R_l = 60 * (V_x - V_y) / (2\pi \cdot R) \cdot \cdot \cdot (19)$$

5 In the above expressions (18) and (19), “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, and $V_x = 0$ and $V_y \neq 0$ are satisfied when assisting the movement in the left-right direction.

[0196]

10 For example, when the controller 4 determines that the bed 10 is moving in the front-rear direction (Step S15 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 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 ($R_r = R_l$).

[0197]

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

[0198]

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 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

25

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 ($R_r = -R_l$).

[0199]

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

[0200]

 Thereafter, in Step S8 following Step S7, the controller 4 performs the safe control
10 process. Details of this process are shown in Steps S51 and S52 of FIG. 17.

[0201]

 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
15 advance in the memory of the controller 4, and is suitably read out as needed.

[0202]

 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.

20 [0203]

 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.

[0204]

25 As described above, the controller 4 according to the present embodiment is configured

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 are equal to or greater than the fifth threshold T5 (Step S51: YES).

[0205]

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 and 22L are driven to reach the commanded rotational speeds R_r and R_l determined in Steps S5, S6, and S7. This provides the assistance in the moving direction.

[0206]

According to the present embodiment described above, detecting the induced current with the first and second current sensors SW1 and SW2 allows estimating torque that causes the induced current (the torque that causes the wheels to rotate). Thus, as shown in Step S3 of FIG. 9, the accelerations a_x and a_y of the bed 10 can be estimated. The accelerations a_x and a_y increase in accordance with the external force applied by the transporter 100. Thus, as shown in Step S33 of FIG. 15, whether the bed 10 is pushed can be determined by determining whether the accelerations a_x and a_y are equal to or greater than the predetermined value.

[0207]

Further, as shown in FIG. 15, the velocity increase control as the second control performed in addition to the compliance control as the first control not only allows the wheels to simply follow the bed 10, but also reduces the load on the transporter 100 by the amount of increase in the commanded rotational speeds by the velocity increase control. This makes it

easier to push the bed 10, and can give the transporter 100 an appropriate “feeling of being assisted.”

[0208]

As shown in Step S33 in FIG. 15, by performing the velocity increase control when
5 the accelerations a_x and a_y are equal to or greater than the fourth threshold, that is, when the bed
10 is pushed, the timing when the transporter 100 pushes the bed 10 and the timing when the
bed 10 becomes easy to push can be synchronized. This can give the transporter 100 an adequate
feeling of being assisted. The transport assistance apparatus 1 is configured to perform the
velocity increase control is performed on condition that the bed 10 is pushed. This can avoid a
10 situation in which the transport assistance apparatus 1 unintentionally travels as a result of the
velocity increase control performed when the target is not pushed.

[0209]

It is also considered that the values detected by the first and second rotation sensors
SW3 and SW4 become higher as the transporter 100 pushes the bed 10 harder. In the present
15 embodiment, as shown in Steps S32 to S34 in FIGS. 13 and 15, the movement of the bed 10 is
assisted with a stronger thrust as the detected values of the rotational speeds increase. This can
provide assistance according to the magnitude of the external force, and advantageously makes
the bed 10 easy to push.

[0210]

20 By implementing the process of Step S35 in FIG. 15, the movement of the bed 10 is
assisted by a weaker thrust when the transporter 100 gently pushes the bed 10 or releases the
hand from the bed 10. This can provide assistance according to the magnitude of the external
force, give the transporter an adequate feeling of being assisted, and keep the transport
assistance apparatus 1 from unintentionally travelling by itself.

25 [0211]

Further, as shown in Steps S4 and S5 of FIG. 9, when the rotational speeds are less than the first threshold T1, driving of the first and second mecanum wheels 21R and 21L as the wheels is limited. This can perform the compliance control and the velocity increase control only in a situation where the bed 10 is actually being transported. This contributes to
5 improvement in usability of the transport assistance apparatus 1.

[0212]

If the velocity increase control is performed when the bed is ascending the slope, the transporter may feel more assisted only at the moment the transporter starts to push the bed 1, but the feeling does not increase after the start (during the uphill travel). Thus, as shown in
10 Steps S41 to S44 of FIG. 16, when it is determined that the bed is ascending the slope, the longitudinal acceleration a_x referred to for the compliance control is increased, and then the compliance control is performed based on the increased longitudinal acceleration a_x' . Increasing the longitudinal acceleration a_x is equivalent to estimating the external force acting on the bed 10 to be larger than the external force actually acting. By estimating the external
15 force to be large, assistance is given to exert a thrust stronger than a thrust to follow the movement of the bed 10. This process is performed as long as the uphill travel continues, and thus continuously provides a good assist feeling while the bed is ascending the slope.

[0213]

If the velocity increase control is performed when the bed 10 is descending the slope,
20 the bed 10 is accelerated more than necessary, and the bed 10 may be separated from the hand of the transporter 100. Thus, as shown in Steps S41 to S45 of FIG. 16, the compliance control alone is performed without increasing the longitudinal acceleration a_x , and the velocity increase control is not performed. This can give the transporter an appropriate feeling of being assisted while descending the slope.

25 [0214]

The safety limit control implemented as shown in FIG. 17 can keep the values of the commanded rotational speeds at the fifth threshold T5 or less. This improves the safety of the transport assistance apparatus 1 more than before.

[0215]

5 The transport assistance apparatus 1 according to the present embodiment can also provide assistance in moving a heavy object such as the bed 10 with casters shown in FIGS. 1 and 2, and the transporter 100 can feel that the bed is easy to push.

[0216]

<Other Embodiments>

10 Although the first and second mecanum wheels 21R and 21L are used as the wheels in the above embodiment, this configuration is not essential. The present disclosure can also be applied to other wheels than the mecanum wheels, such as omni wheels. The number of wheels is not limited to two. For example, when the mecanum wheels are used as in the present embodiment, four mecanum wheels may be used. When the omni wheels are employed, three
15 or four omni wheels may be used. The number of motors may be changed according to the number of wheels.

[0217]

 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
20 essential.

[0218]

 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
25 between Steps S31 and S32.

DESCRIPTION OF REFERENCE CHARACTERS

[0219]

	1	Transport Assistance Apparatus
5	4	Controller
	10	Bed (Target, Bed with Casters)
	14	Caster
	14F	Front Caster
	14B	Rear Caster
10	21R	First Mecanum Wheel (Wheel)
	211R	First Wheel Body
	212R	First Barrel-Shaped Roller
	21L	Second Mecanum Wheel (Wheel)
	211L	Second Wheel Body
15	212L	Second Barrel-Shaped Roller
	22R	First Motor (Motor)
	22L	Second Motor (Motor)
	SW1	First Current Sensor (Current Sensor)
	SW2	Second Current Sensor (Current Sensor)
20	SW3	First Rotation Sensor (Rotation Sensor)
	SW4	Second Rotation Sensor (Rotation Sensor)
	SW5	Six-Axis Sensor (Inclination Sensor)

CLAIMS

[Claim 1] A transport assistance apparatus for assisting a movement of a target made by an external force, the transport assistance apparatus comprising:

- 5 a wheel attached to the target;
- a motor connected to the wheel to drive the driving wheel;
- a current sensor that detects an induced current flowing through the motor when the wheel rotates; and
- a controller that controls the motor,
- 10 wherein
- the controller
- estimates an acceleration of the target based on a detection signal of the current sensor,
- performs first control of commanding a rotational speed of the motor based
- 15 on the acceleration to follow the movement of the target, and
- performs second control of increasing the commanded rotational speed set in the first control when it is determined that an absolute value of the acceleration is equal to or greater than a predetermined value.

- 20 [Claim 2] The transport assistance apparatus of claim 1, further comprising:
- a rotation sensor that detects a rotational speed of the wheel,
- wherein
- when increasing the commanded rotational speed, the controller increases the commanded rotational speed as the rotational speed detected by the rotation sensor increases.

25

[Claim 3] The transport assistance apparatus of claim 1, wherein
the controller reduces the commanded rotational speed after the second control when
the absolute value of the acceleration falls below the predetermined value.

5 [Claim 4] The transport assistance apparatus of claim 1, further comprising:
a rotation sensor that detects a rotational speed of the motor,
wherein
the controller permits driving of the wheel on condition that the rotational speed is
equal to or greater than a predetermined value based on a detection signal of the rotation sensor.

10

[Claim 5] The transport assistance apparatus of claim 1, further comprising:
a rotation sensor that detects a rotational speed of the motor; and
an inclination sensor that detects an inclination angle of a transport surface on which
the target travels,

15

wherein
the controller determines whether the transport surface is a slope based on a detection
signal of the inclination sensor,

when it is determined that the transport surface is not the slope, the controller performs
both the first control and the second control based on the acceleration obtained by the current
20 sensor, and

when it is determined that the transport surface is the slope, the controller determines
whether the target is ascending the slope based on the detection signals of the rotation sensor
and the inclination sensor; and when it is determined that the target is ascending the slope, the
controller increases the acceleration obtained by the current sensor and performs the first
25 control based on the increased acceleration without performing the second control.

[Claim 6] The transport assistance apparatus of claim 1, further comprising:
a rotation sensor that detects a rotational speed of the wheel; and
an inclination sensor that detects an inclination angle of a transport surface on which
5 the target travels,
wherein
the controller determines whether the transport surface is a slope based on a detection
signal of the inclination sensor,
when it is determined that the transport surface is not the slope, the controller performs
10 both the first control and the second control based on the acceleration obtained by the current
sensor, and
when it is determined that the transport surface is the slope, the controller determines
whether the target is descending the slope based on the detection signals of the rotation sensor
and the inclination sensor; and when it is determined that the target is descending the slope, the
15 controller performs the first control based on the acceleration obtained by the current sensor
without performing the second control.

[Claim 7] The transport assistance apparatus of claim 1, wherein
after the second control, the controller
20 maintains a value of the commanded rotational speed when the commanded
rotational speed is less than a predetermined threshold, and
changes the commanded rotational speed to the threshold when the
commanded rotational speed is equal to or greater than the threshold.

25 [Claim 8] The transport assistance apparatus of any one of claims 1 to 7,

wherein

the target is a bed with casters, and

the wheel is attached to a lower portion of the bed with casters.