

POWERED CASTER WHEEL ASSEMBLY

FIELD OF INVENTION

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The present invention broadly relates to powered caster wheel assemblies.

BACKGROUND

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Omni-directional wheeled mobile platforms have been an active research area over the past three decades. Their advantages over the legged platforms are the cost-effectiveness, high loading capacity, high efficiency, ease of control, and the ability to perform tasks in congested and narrow environment. To construct an omni-directional wheeled mobile platform, three classes of wheels can be employed, i.e. the conventional wheels, special-design omni-directional wheels, and ball wheels. Conventional wheels are those with simple disk geometry that we see everyday, such as those on cars and trolleys. Omni-directional wheels mainly refer to the Mekanum wheels, consisting of a drum with a plurality of idle rollers located on its periphery. Since all the roller axes are skewed with respect to the axis of the drum, the wheel can allow omni-directional motions. The ball wheels can be treated as a special type of omni-directional wheels with ball shaped geometry.

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The ball wheels are difficult to implement, as it is not possible to place an axle through the ball without sacrificing the usable workspace. Moreover, it is difficult to transmit power to drive the wheels. There is also the practical need of keeping them robust from collected dust and dirt from the floor.

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The omni-directional wheels tend to have low loading capacity and poor ground clearance due to the use of small peripheral rollers and the arrangement of the support structure being very close to the ground. Moreover, they have the drawback of

discontinuous wheel contact points because of the changing support provided, which may cause a lot of vibration.

Consequently, the conventional wheels are the simplest and most robust among
5 the wheel designs. United States Patent No. 6491127 discloses a novel Powered Caster
Wheel (PCW) module design based on a conventional wheel for omni-directional mobile
robot platforms, comprising motorized caster wheel with a lateral offset between the
steering and rolling axis. Two rotary motors are mounted side by side in a vertical
arrangement, one for independent driving and another for independent steering.
10 However, turning the steering axis not only changes the direction of the wheel but also
induces a displacement orthogonal to the direction of wheel.

While the PCW has been widely accepted for various omni-directional mobile
platforms to provide full mobility and agility, there are some problems in the current PCW
15 design. One of the major problems is the abovementioned coupling effect between
steering and rolling of the wheel such that the steering motion of the wheel always
induces a rolling motion.

Although a control technique can be employed to overcome this coupling effect,
20 control errors always exist. In addition, such a control solution also requires costly
motion control hardware and/or software and/or electronic circuitry. For example, both
the steering and rolling motors may have to be servomotors. Additional power is wasted
to counter the rolling motion that is not intended for the actual motion control.

25 A need therefore exists to provide a system that seeks to address at least one of
the above problems.

30 SUMMARY

In accordance with a first aspect of the present invention, there is provided a
powered caster wheel assembly comprising a first actuator for driving a wheel; a

second actuator for steering the wheel; and a mechanical compensating mechanism coupled between the second actuator and the wheel; wherein the mechanical compensating mechanism is arranged for driving the wheel to counter a driving motion of the wheel induced by steering.

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The mechanical compensating mechanism may comprise a first mechanical power transmission system for transferring a rotational movement of a first vertical axis coupled to the second actuator into a rotational movement of a second vertical axis coupled to the first actuator.

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The first mechanical power transmission system may comprise a first pulley-belt set, wherein an output pulley of the first pulley-belt set comprises a ring gear coupled to a planetary gear set, and a carrier coupled to the planetary gear set and to the second vertical axis.

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The first mechanical power transmission system may comprise a first gear train, wherein an output gear of the first gear train comprises a ring gear coupled to a planetary gear set, and a carrier coupled to the planetary gear set and to the second vertical axis.

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The first gear train may comprise an external gear coupled to an internal gear.

The first gear train may comprise an input gear coupled to an idle gear coupled to an output gear.

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The second vertical axis may be coupled to a bevel gear set for transforming a rotation of the second vertical axis into a rotation around a horizontal axis.

The second vertical axis may be coupled to a helical gear set for transforming a rotation of the second vertical axis into a rotation around a horizontal axis.

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The second vertical axis may be coupled to the first actuator in a manner such that the second vertical axis can be independently driven by the first actuator and by the first mechanical power transmission system of the mechanical compensating mechanism.

The second vertical axis may be coupled to the first actuator by a second mechanical power transmission system comprising a second pulley-belt set coupled to a sun gear coupled to the planetary gear set and the carrier coupled to the planetary gear set.

The second vertical axis may be coupled to the first actuator by a second mechanical power transmission system comprising a second gear train coupled to a sun gear coupled to the planetary gear set and the carrier coupled to the planetary gear set.

The first actuator and the second actuator may comprise respective rotary motors.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

Figure 1A is a front view of a powered caster wheel assembly according to an example embodiment;

Figure 1B is a left view of the powered caster wheel assembly of Figure 1A;

Figure 1C is a back view of the powered caster wheel assembly of Figure 1A;

Figure 2A is a kinematic diagram of a powered caster wheel assembly according to an example embodiment;

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Figure 2B is a side view of the wheel portion of Figure 2A;

Figure 3A is a kinematic diagram of a gear train comprising an external gear coupled to an internal gear according to an example embodiment; and

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Figure 3B is a kinematic diagram of a gear train comprising an input gear coupled to an idle gear to an output gear according to an example embodiment.

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DETAILED DESCRIPTION

Figure 1A is a front view of a powered caster wheel assembly 100 according to an example embodiment. Figure 1B is a left view of the powered caster wheel assembly 100 of Figure 1A. Figure 1C is a back view of the powered caster wheel assembly 100 of Figure 1A.

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The powered caster wheel assembly 100 comprises a first actuator 102 and a second actuator 104 for driving and steering a caster wheel 108 respectively; and a mechanical compensating mechanism 106 coupled between the second actuator 104 and the caster wheel 108. The mechanical compensating mechanism 106 is arranged for driving the caster wheel 108 to counter a rolling motion of the caster wheel 108 induced by steering. The powered caster wheel assembly 100 further comprises structural elements such as mounting plates 110, 112, support column 120.

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With reference to Figure 2A, the working of the caster wheel assembly 100 and the mechanical compensating mechanism 106 is now described in detail. The assembly 100 comprises mechanical power transmission systems capable of transmitting mechanical power between two parallel shafts with same the rotation direction and constant velocity ratio. In the example embodiment, the mechanical power transmission systems are in the form of pulley-belt sets 210, 220, 230, 240 comprising input pulleys 212, 222, 232, 242, output pulleys 214, 224, 234, 244 and belts 216, 226, 236, 246 respectively. The output pulley 224 is in the form of a gear mesh 260 including sun gear 262, planetary gears 264 and ring gear 268.

In alternate embodiments, gear trains including but not limited to ones comprising an external gear coupled to an internal gear (as shown in Figure 3A), or an input gear coupled to an idle gear coupled to an output gear (as shown in Figure 3B), can be used in place of the pulley-belt sets 210, 220, 230 and 240, and a helical gear set in place of the bevel gear set 250. For example, the external gear 302 in Figure 3A may correspond to any one of the input pulley 212, 222, 232 or 242, and the internal gear 304 may correspond to any one of the output pulley 214, 224, 234 or 244. It will be appreciated that a rotation of the external gear 302 drives the internal gear 304 in the same rotation direction due to an internal arrangement. In Figure 3B, the input gear 312 may correspond to any one of the input pulley 212, 222, 232 or 242, and the output gear 316 may correspond to any one of the output pulley 214, 224, 234 or 244. It will be appreciated that the input gear 312, the idle gear 314 and the output gear 316 are in an external arrangement such that input gear 312 and output gear 316 rotate in the same direction with a constant velocity ratio independent of the idle gear 314. If a gear train is used in place of the pulley-belt set 220, an output gear can be in the form of the gear mesh including sun gear 262, planetary gears 264 and ring gear 268.

In the example embodiment, the first actuator 102 and the second actuator 104 comprise rotary motors. The first actuator 102 is employed for generating a rolling motion of the caster wheel 108 for driving the caster wheel assembly 100. Starting from the first actuator 102, rotational movement about a vertical axis is directly transmitted to

the input pulley 212 which is axially coupled to an output shaft of the first actuator 102. As would be appreciated by a person skilled in the art, the rotational movement of the input pulley 212 is mechanically transmitted to the output pulley 214 through belt 216, which is in frictional contact with both pulleys 212 and 214, such that pulleys 212 and
5 214 rotate in the same direction and at a constant velocity ratio.

The output pulley 214 is axially coupled to a sun gear 262 such that the sun gear 262 rotates in tandem, i.e. in the same direction and at the same angular velocity, with the output pulley 214. At the planetary gear set 260, the sun gear 262, in turn, drives
10 planetary gears 264 in a two degree-of-freedom (2-DOF) motion, i.e. a rotation about their own axes and a circular motion around the external circumference of the sun gear 262 in an opposite direction to the rotation of the sun gear 262. It would be appreciated by a person skilled in the art that at least two planetary gears 264 are employed. The planetary gears 264 are coupled to a carrier 266 such that the circular motion of the
15 planetary gears 264 around the circumference of the sun gear 262 is translated to a rotation of the carrier 266.

Furthermore, the carrier 266 is axially coupled to a first bevel gear 252 such that the first bevel gear 252 rotates in tandem with the carrier 266. The rotation of
20 the first bevel gear 252 about a vertical axis is then converted to a rotation of a second bevel gear 254 about a horizontal axis as bevel gears 252 and 254 are perpendicularly engaged.

The second bevel gear 254 is axially coupled to the input pulley 242 such
25 that the input pulley 242 rotates in tandem with the second bevel gear 254. The rotation is transmitted to the output pulley 244 in a same manner as described above for the pulley-belt set 210. Finally, the output pulley 244 is axially coupled to the caster wheel 108 such that the caster wheel 108 rotates in tandem with the output pulley 244 about a horizontal axis.

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As described above, rotational movement of the first actuator 102 is transmitted through the pulley-belt set 210, the planetary gear set 260, the bevel

gear set 250 and the pulley-belt set 240 to the caster wheel 108 for generating a rotation of the caster wheel 108 about a horizontal axis 270 for driving the assembly 100 backward and forward.

5 For steering, rotational movement of the second actuator 104 about a vertical axis is directly transmitted to the input pulley 232 which is axially coupled to an output shaft of the second actuator 104. The rotational movement is then transmitted to the output pulley 234 via the belt 236. With reference to Figure 2B, the caster wheel 108 is rigidly mounted to the output pulley 234 by a wheel frame
10 109 (as shown in Figure 1A), such that the caster wheel 108 rotates in tandem with the output pulley 234, thereby allowing the caster wheel 108 to be steered about a vertical axis through the center of the output pulley 234. A rolling motion of the caster wheel 108 would also be induced due to a rotation of the second bevel gear 254 around the stationary first bevel gear 252 when the caster wheel 108 and wheel
15 frame 109 are steered about the vertical axis through the center of the output pulley 234.

In the example embodiment, the rotational movement of the second actuator 104 is advantageously transmitted to the compensating mechanism 106 for
20 generating a motion to counter or compensate the induced rolling motion. From the input pulley 222, which is axially coupled to actuator 104 and input pulley 232, the rotational movement is transmitted to the output pulley 224 through the belt 226. The output pulley 224 includes the ring gear 268 such that the ring gear 268 rotates with the output pulley 224.

25 The ring gear 268 then drives the planetary gears 264 in another 2-DOF motion, i.e. a rotation about their axes and a circular motion around the internal circumference of the ring gear 268 in the same direction as the rotation of the ring gear 268. The rotational movement is transferred through the carrier 266 to the first
30 bevel gear 252 for generating, independent from the first actuator 102, a rotation of the second bevel gear 254 that "matches" the rotation induced during steering. This

effectively minimises or removes the rolling motion of the caster wheel 108 induced by steering.

For example, from a clockwise rotational movement of the second actuator 104,
 5 the caster wheel 108 and wheel frame 109 are steered clockwise. At the same time, the second bevel gear 254 moves in a 2-DOF motion, i.e. a clockwise circular motion about the vertical axis through the center of output pulley 234 and a clockwise rotation about its own axis. Therefore, a rolling motion of the caster wheel 108 would be induced. In the powered caster wheel assembly 100 according to the example embodiment, the
 10 clockwise rotational movement of the second actuator 104 is also transmitted through the pulley-belt set 220, the planetary gear set 260 resulting in a clockwise rotation of the first bevel gear 252, which in turn causes a counter-clockwise rotation of the second bevel gear 254 to minimise and preferably eliminate the net rotational movement of the second bevel gear 254. By selecting the appropriate kinematic parameters such that the
 15 counter-clockwise rotation equals the clockwise rotation, total compensation can preferably be achieved in an example embodiment, thereby completely removing any induced rolling during steering.

The removing of the induced rolling motion of the caster wheel 108 is
 20 dependent on kinematic parameters of the compensating mechanism, as described in detail in the following section. Therefore, it is possible to select the appropriate parameters, e.g. gear ratios, for completely removing unwanted induced rolling motion during steering.

25 In the description that follows, the relevant nomenclatures are necessary for understanding the powered caster wheel assembly of the present invention:

ω_d – the input angular velocity of the first actuator 102
 ω_s – the input angular velocity of the second actuator 104
 30 ω_{wr} – the output angular velocity of the rolling motion of the caster wheel 108
 ω_{ws} – the output angular velocity of the steering motion of the caster wheel 108

ω_{rs} – the angular velocity of the rolling motion of the wheel 108 induced by the steering motion

$i_{p1} = \frac{z_{p2}}{z_{p1}}$ – the gear ratio of the pulley-belt set 210 where z_{p1} and z_{p2} represent the teeth numbers of pulleys 212 and 214 respectively.

5 $i_{p2} = \frac{z_{p4}}{z_{p3}}$ – the gear ratio of the pulley-belt set 220 where z_{p3} and z_{p4} represent the teeth numbers of pulleys 222 and 224 respectively.

$i_{p3} = \frac{z_{p6}}{z_{p5}}$ – the gear ratio of the pulley-belt set 230 where z_{p5} and z_{p6} represent the teeth numbers of pulleys 232 and 234 respectively.

10 $i_{p4} = \frac{z_{p8}}{z_{p7}}$ – the gear ratio of the pulley-belt set 240 where z_{p7} and z_{p8} represent the teeth numbers of pulleys 242 and 244 respectively.

$i_b = \frac{z_{b2}}{z_{b1}}$ – the gear ratio of the bevel gear set 250 where z_{b1} and z_{b2} represent the teeth numbers of bevel gears 252 and 254 respectively.

15 $\alpha = \frac{z_r}{z_s}$ – the characteristic parameter of planetary gear set 260 where z_r and z_s represent the teeth numbers of ring gear 268 and sun gear 262 respectively.

Based on the notations listed above, the output angular velocity of the steering motion ω_{ws} is given by:

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$$\omega_{ws} = \frac{\omega_s}{i_{p3}} \quad (1)$$

Equation (1) indicates that the steering motion only depends on the rotational movement of the second actuator 104. However, the steering motion induces an additional rolling motion, ω_{rs} , which is written as:

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$$\omega_{rs} = -\frac{\omega_s}{i_{p3}i_b i_{p4}} \quad (2)$$

Therefore, the output angular velocity of the rolling motion of the wheel 208 is given by:

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$$\omega_{wr} = \frac{\frac{\omega_r}{i_{p1}} + \frac{\alpha\omega_s}{i_{p2}}}{(1+\alpha)i_b i_{p4}} + \omega_{rs} = \frac{\frac{\omega_r}{i_{p1}} + \frac{\alpha\omega_s}{i_{p2}}}{(1+\alpha)i_b i_{p4}} - \frac{\omega_s}{i_{p3}i_b i_{p4}} = \frac{\omega_r}{(1+\alpha)i_b i_{p1} i_{p4}} + \frac{[\alpha i_{p3} - (1+\alpha)i_{p2}]\omega_s}{(1+\alpha)i_b i_{p2} i_{p3} i_{p4}} \quad (3)$$

Equation (3) indicates that the resultant rolling motion of the wheel 208 depends on the motion inputs from both the first actuator 202 and the second actuator 204. However, the rolling motion induced by the steering input by the second actuator 204 may be removed
 5 when the following condition is satisfied:

$$\alpha i_{p3} - (1 + \alpha) i_{p2} = 0 \quad (4)$$

Rearranging Equation (4) yields:

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$$\alpha = \frac{i_{p2}}{i_{p3} - i_{p2}} \quad (5)$$

From Equation (5), it can be derived that if the values of α , i_{p2} , and i_{p3} are appropriately selected to make Equation (5) valid, the rolling motion induced by the motion input of the second actuator 204 may be completely removed. In other words, to achieve pure rolling
 15 and pure steering characteristics for the powered caster wheel 108, only one equation, i.e. Equation (5), needs to be satisfied, which only involves three kinematic parameters to satisfy one equation. Therefore, embodiments of the system 100 of the present invention possess high flexibility for performance optimization by adjusting the
 20 independent parameters.

When Equation (5) is satisfied, the output angular velocity of the rolling motion is given by:

$$25 \quad \omega_{wr} = \frac{\omega_r}{(1 + \alpha) i_b i_{p1} i_{p4}} \quad (6)$$

The powered caster wheel assembly according to embodiments of the present invention may be suitable for a wide spectrum of omni-directional mobile platforms ranging from high-end mobile robots to low-end wheel chairs. The major merit of the
 30 powered caster wheel assembly according to embodiments of the present invention is

that any induced rolling motion during steering is removed so that the steering and rolling motions can be precisely and independently controlled, achieving decoupled steering and rolling motions.

5 Further advantages of the PCW assembly according to embodiments of the present invention are as follows. The actuators may be independently controlled as the mechanical compensation of the induced rolling is dependent only on kinematic parameters such as gear ratios. Hence the control scheme may be simplified and slip and slid motions may be reduced. The two actuators may be mounted onto a fixed base
10 so as to improve the power transmission efficiency and simplify the wiring scheme. Additionally, a number of pulley-belt drives are employed and may be able to reduce the shock and vibration of the system, while offering the advantage of ease of assembly, maintenance, and power transmission ratio readjustment. However, for applications to heavy mobile platforms, the pulley-belt drives may be replaced with gear trains. The
15 kinematic parameters may be flexibly adjusted to achieve optimized performance. The pure rolling and steering motion characteristic is independent of the offset between the rolling and steering axis. As a result, the offset may be free for adjustment increasing design flexibility.

20 It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

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CLAIMS

1. A powered caster wheel assembly comprising:
a first actuator for driving a wheel;
5 a second actuator for steering the wheel; and
a mechanical compensating mechanism coupled between the second actuator and the wheel;

wherein the mechanical compensating mechanism is arranged for driving the wheel to counter a driving motion of the wheel induced by steering.

2. The powered caster wheel assembly as claimed in claim 1, wherein the mechanical compensating mechanism comprises a first mechanical power transmission system for transferring a rotational movement of a first vertical axis coupled to the second actuator into a rotational movement of a second vertical axis coupled to the first actuator.

3. The powered caster wheel assembly as claimed in claim 2, wherein the first mechanical power transmission system comprises a first pulley-belt set, wherein an output pulley of the first pulley-belt set comprises a ring gear coupled to a planetary gear set, and a carrier coupled to the planetary gear set and to the second vertical axis.

4. The powered caster wheel assembly as claimed in claim 2, wherein the first mechanical power transmission system comprises a first gear train, wherein an output gear of the first gear train comprises a ring gear coupled to a planetary gear set, and a carrier coupled to the planetary gear set and to the second vertical axis.

5. The powered caster wheel assembly as claimed in claim 4, wherein the first gear train comprises an external gear coupled to an internal gear.

6. The powered caster wheel assembly as claimed in claim 4, wherein the first gear train comprises an input gear coupled to an idle gear coupled to an output gear.

5 7. The powered caster wheel assembly as claimed in claims 3 or 4, wherein the second vertical axis is coupled to a bevel gear set for transforming a rotation of the second vertical axis into a rotation around a horizontal axis.

10 8. The powered caster wheel assembly as claimed in claims 3 or 4, wherein the second vertical axis is coupled to a helical gear set for transforming a rotation of the second vertical axis into a rotation around a horizontal axis.

15 9. The powered caster wheel assembly as claimed in any one of claims 2 to 8, wherein the second vertical axis is coupled to the first actuator in a manner such that the second vertical axis can be independently driven by the first actuator and by the first mechanical power transmission system of the mechanical compensating mechanism.

20 10. The powered caster wheel assembly as claimed in claim 9, wherein the second vertical axis is coupled to the first actuator by a second mechanical power transmission system comprising a second pulley-belt set coupled to a sun gear coupled to the planetary gear set and the carrier coupled to the planetary gear set.

25 11. The powered caster wheel assembly as claimed in claim 9, wherein the second vertical axis is coupled to the first actuator by a second mechanical power transmission system comprising a second gear train coupled to a sun gear coupled to the planetary gear set and the carrier coupled to the planetary gear set.

30 12. The powered caster wheel assembly as claimed in any one of claims 1 to 11, wherein the first actuator and the second actuator comprise respective rotary motors.