Title: SELF-PIVOTING DRIVE FOR SPHERICAL-FORM MOTION SIMULATORS

Abstract: This mechanism for driving motions of a surface of spherical, ellipsoidal, plane, or other shape comprises a pair of drive wheels mounted on a freely pivoting frame, each wheel being driven by its own bidirectional motor. The motors and the active electronics of an angle encoder are mounted in an associated fixed frame, so no slip rings or other rotating connections are needed for motor power and control, or for determining the rotation angle of the pivoting frame. Control of the motors provides differential rotation of the two wheels to effect controlled rotation of the pivoting frame, and therefore of wheel direction. This avoids the use of a separate motor for changing the direction of motion of the surface.
TITLE OF THE INVENTION

SELF-PIVOTING DRIVE FOR SPHERICAL-FORM MOTION SIMULATORS
CROSS-REFERENCE TO RELATED APPLICATIONS

U.S. PATENT DOCUMENTS

This patent claims the benefit of U.S. provisional patent No. 62/117,491 filed on February 18, 2015, which is herein incorporated by reference.

5,490,784 2/1996 Carmein Virtual reality system with enhanced sensory apparatus 434/29
6,629,896 10/2003 Jones Nimble virtual reality capsule using rotatable drive assembly 472/60
61/946,685 02/2014 Harris Children's three-axis ride controlled by smart-tablet app
STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

- Not applicable -

REFERENCE TO SEQUENCE LISTING, A TABLE, OR A COMPUTER PROGRAM LISTING COMPACT DISC APPENDIX

- Not applicable -

STATEMENT REGARDING PRIOR DISCLOSURE BY THE INVENTOR

There have been no prior disclosures by the inventor.
BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

[0001] This invention relates generally to mechanisms for driving motion simulators such as those of virtual reality systems, flight simulators, and interactive game seats. It is a simple mechanism for rotating a simulator with an exterior shell which is part or all of a sphere. It preferably would be used with a second such mechanism to drive a spherical surface in any variable rotation.

THE PRIOR ART

[0002] U.S. patents 5,490,784 and 6,629,896 show motion simulators which have spherical exterior shells and a support arrangement that includes rotatable drive wheels. In both of these, rotation of the sphere is driven by the drive wheels in frictional contact with the spherical surface. The drive wheel is mounted so the axis of wheel rotation, can be rotated about the line perpendicular to the sphere's surface at the point at which the wheel contacts the surface. Both patents use one motor for rotation of the drive wheel, and another motor for rotation of the wheel's axis. Patent 5,490,784 shows an arrangement with differentially-coupled double wheels driven by a single motor, plus a second motor for rotation of the wheel axis; the rotations of the wheels are not independent.
In contrast to prior art, the present invention has a common-axis double-wheel arrangement with each wheel driven by a separate motor. The wheels are mounted on a pivoting frame which freely rotates about a line perpendicular to the axis of the wheels. In application, the two wheels are in frictional contact with the driven surface, so controlled differential rotation of the wheels is used to set the direction of the axis of the wheels. The surface can be part or all of a sphere, but the invention can be applied to other surfaces, including, but not limited to cylinders, ellipsoids, and planes. In the following, the term "sphere" will be used to mean any such surface.

The sphere rotates when the two wheels of the invention turn in the same direction. The arrangement is symmetrical, and the two motors work together to drive the rotation of the sphere. Thus, two small motors rather than one larger motor can be used for sphere rotation; an additional motor for moving of the wheel axis is not necessary.

The invention includes an angle encoder measuring the direction of wheel action. The active electronics of the angle encoder are mounted on the rigidly-mounted frame.

The connections between the rigidly-mounted frame and the pivoting frame that supports the wheels are all mechanical. Thus, all electrical connections to the the motors and angle encoder arise in a rigidly-mounted frame, so no slip-rings or other rotating connections are needed. This is an important, unique feature of the invention.

Both the foregoing summary and the detailed description which follows are exemplary and explanatory only, and they are not to be considered restrictive of the invention as claimed. The figures are schematic, and are not to be considered complete plans or drawings suitable for production of the invention.
BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0008] FIG. 1 shows one embodiment of the invention in two views. One view is a half-sectional view showing the exterior appearance of the invention, and the gear arrangement viewed in one direction; the other is an entire cross-section viewed in another direction. The cross-sectional part of the half-sectional view is broken in three places to simplify display of gear and wheel positions. The broken-out parts are rotated to correspond with the angled part of section line A-A.

[0009] FIG. 2 displays a wheel. It shows the ring gear and the clearance slot for the spur gear which meshes with the ring gear.

[0010] Fig. 3 is a cross-section view of another embodiment of the invention. This embodiment does not require the shaft driven by one motor to pass through the shaft of the other motor.
[0011] **Fig.** 1 shows two views of the invention, each of the views showing parts of the mechanism. The view on the right side is a cross-sectional view at the plane midway between the wheels. The view on the left side is a half-sectional view taken along section line A-A shown in the right view.

[0012] Mounting plate 76, only part of which is shown in the figures, rigidly attaches to and supports fixed frame 80. **Fig.** 3, which shows an embodiment different from that of **Fig.** 1, displays only part of fixed frame 80. For any embodiment, the fixed frame is the rigid mount for the bidirectional electric motors 100 and 101, and their associated gear boxes 102 and 103, respectively. The active electronics of angle encoder 75 is rigidly attached to fixed frame 80. That frame is closed by outside end cap 82 (not shown in **Fig.** 3). Flange 81 (not shown in **Fig.** 3) is for clamping fixed frame 80 to mounting plate 76.

[0013] Thrust bearing 73 and clearance gap 74 provide for mounting the pivoting frame 50 so it can rotate about the centerline of fixed frame 80. The pivoting frame is closed by inside end cap 83.

[0014] The drive wheels 52 and 53 with wheel bearings 55 are mounted on axles 56 rigidly fixed to pivoting frame 50. The axle and wheel bearings can be seen in the cross section of wheel 53. Each wheel has a tire 54 for contacting the spherical surface 84.

[0015] As **Fig.** 2 shows, each wheel has a ring gear 57. For each drive wheel there is a drive train which turns the wheel using a spur gear acting on the ring gear. Each wheel also has a clearance slot 59 for the spur gear and shaft end.

[0016] There is a concentric pair of drive shafts: outer longitudinal drive shaft 65, and inner longitudinal drive shaft 64. These are coincident with the axis of rotation of pivoting frame 50, and they pass
from the interior of fixed frame 80 into the interior of pivoting frame 50. Each of the motors rotates one of these drive shafts.

[0017] Consider the drive train for wheel 53. Helical gear 67 is rigidly affixed to the outer longitudinal drive shaft 65, and it meshes with helical gear 63. Shaft 61 is rigidly affixed to both helical gear 63 and spur gear 58. The latter meshes with ring gear 57 rigidly affixed to wheel 53. Therefore, as outer longitudinal drive shaft 65 rotates, all of these elements, including wheel 53, rotate correspondingly.

[0018] Similarly, the drive train for wheel 52 has the inner longitudinal drive shaft 64 rigidly affixed to helical gear 66, which meshes with helical gear 62. Shaft 60 is rigidly affixed to both helical gear 62 and a spur gear (not shown). The latter meshes with the ring gear (not shown) rigidly affixed to wheel 52. Therefore, as inner longitudinal drive shaft 64 rotates, all of these elements, including wheel 52, rotate correspondingly.

[0019] A preferred arrangement is to have the gears arranged so that concentric shafts 64 and 65 rotate in the same direction when wheels 52 and 53 are also rotating in the same direction. This reduces frictional losses between the two concentric shafts during sphere rotation (but not, of course, when the wheel rotation is differential). It requires one pair of helical gears to be right-handed, the other pair to be left-handed.

[0020] Figs. 1 and 3 show two different arrangements for the motors. In Fig. 1 the motors are aligned concentrically. The hollow shaft from gearbox 102 on motor 100 is extended to become the outer longitudinal drive shaft 65. The shaft from gearbox 103 on motor 101 passes through hollow shafts associated with motor 100 and gearbox 102, including outer longitudinal drive shaft 65, becoming inner longitudinal drive shaft 64.

[0021] The advantage of the arrangement in Fig. 1 is compactness: fixed frame 80 can be cylindrical.
The disadvantage is that it requires special motors with hollow shafts.

[0022] In Fig. 3 a gear arrangement is used to couple the motors to the drive shafts. Shaft 104 from gearbox 102 on motor 100 is rigidly affixed to spur gear 92. The latter meshes with spur gear 90 which is rigidly affixed to outer longitudinal drive shaft 65. Similarly, shaft 105 from gearbox 103 on motor 101 is rigidly affixed to spur gear 93. The latter meshes with spur gear 91, which is rigidly affixed to inner longitudinal drive shaft 64. Thus, each motor drives the corresponding gear train and wheel.

[0023] The advantage of the arrangement in Fig. 3 is that it can be constructed using conventional motors. The main disadvantage is that it is not as compact as that of Fig. 1.

[0024] Several thrust bearings and spacers keep the longitudinal drive shafts in position. Thrust bearings 71 and 72 and associated spacers 68 and 69 inside of pivoting frame 50 prevent downward motion of the longitudinal drive shafts, and provide the force necessary to hold pivoting frame 50 against thrust bearing 73. Spacer 69 has seats for the hub of helical gear 67 and thrust bearing 72; these prevent lateral motion of the outer longitudinal drive shaft. Radial bearing 70 held in place by inside end cap 83 at the upper end of inner longitudinal drive shaft 64 maintains lateral alignment of the shaft at that end.

[0025] In Fig. 1, upward motion is prevented by thrust bearing 77 associated with the end of inner longitudinal drive shaft 64 protruding from the lower end of motor 101.

[0026] In Fig. 3, upward motion is limited by thrust bearings 94 and 95. Thrust bearing mounts 96 and 97 are rigidly affixed to spur gear 90, and thrust bearing mount 98 is rigidly affixed to spur gear 91. The combination of thrust bearing mounts and associated thrust bearings prevents lateral motion of the shafts, so proper meshing of the gears is maintained.
It will be apparent to persons familiar with the appropriate art that the helical-gear arrangements shown in Figs. 1 and 3 can be replaced with worm drive arrangements; e.g., helical gear 67 replaced with a worm screw, and helical gear 63 replaced with a worm gear.
CLAIMS

Claim 1. A surface-moving mechanism comprising

- a pair of axially-aligned wheels for frictionally moving a surface, said wheels each having a ring gear rigidly affixed to the wheel;
- an axle for each of the said wheels;
- a pivoting frame supporting the two axles;
  for each of said wheels, a spur gear meshing with the ring gear of the wheel, said spur gear rigidly affixed to a shaft which is parallel to the axles of said wheels and mounted for shaft rotation within the pivoting frame, said shaft being referred to as a spur-gear shaft;
- a concentric pair of drive shafts with axis perpendicular to the axles of the wheels, each drive shaft associated with one of the said spur-gear shafts;
  for each drive shaft, a rotation-transfer mechanism by which rotation of the drive shaft effects corresponding rotation of the spur-gear shaft associated with the drive shaft;
- a fixed frame;
  a pair of motors mounted in the fixed frame, each motor associated with one of the concentric drive shafts;
  a thrust bearing between the fixed frame and the pivoting frame, said thrust bearing providing for rotation of the pivoting frame relative to the fixed frame, with the concentric drive shafts passing through the center of the thrust bearing;
  for each drive shaft, a mechanism by which the drive shaft is rotated by the motor associated with the drive shaft; and
  an angle encoder mounted on the fixed frame, said angle encoder determining the angle of rotation of the pivoting frame relative to the fixed frame.

Claim 2. A mechanism as in Claim 1 for which the rotation-transfer mechanism for a drive shaft comprises a helical gear on the drive shaft meshing with a helical gear on the spur-gear shaft associated with the drive shaft.
Claim 3. A mechanism as in Claim 1 for which the rotation-transfer mechanism for a drive shaft comprises a worm screw on the drive shaft and a corresponding worm wheel on the spur-gear shaft associated with the drive shaft.

Claim 4. A mechanism as in Claim 1 for which the mechanism by which a drive shaft is rotated by a motor is a direct connection between the drive shaft and motor or gearbox associated with the drive shaft.

Claim 5. A mechanism as in Claim 1 for which the mechanism by which a drive shaft is rotated by a motor comprises a gear mounted on the drive shaft and a corresponding gear mounted on the shaft of the motor or gearbox associated with the drive shaft, the gear on the drive shaft being driven by the other gear.
Claim 1. A surface-moving mechanism comprising

- a pair of axially-aligned wheels for frictionally moving a surface, said wheels each having a ring gear rigidly affixed to the wheel;
- an axle for each of the said wheels;
- a pivoting frame supporting the two axles;

  for each of said wheels, a spur gear meshing with the ring gear of the wheel, said spur gear rigidly affixed to a shaft which is parallel to the axles of said wheels and mounted for shaft rotation within the pivoting frame, said shaft being referred to as a spur-gear shaft;

- a concentric pair of drive shafts with axis perpendicular to the axles of the wheels, each drive shaft associated with one of the said spur-gear shafts;

  for each drive shaft, a rotation-transfer mechanism by which rotation of the drive shaft effects corresponding rotation of the spur-gear shaft associated with the drive shaft;

  said rotation-transfer mechanism for a drive shaft comprising a helical gear on the drive shaft meshing with a helical gear on the spur-gear shaft associated with the drive shaft;

- a fixed frame;

  a pair of motors mounted in the fixed frame, each motor associated with one of the concentric drive shafts;

  a thrust bearing between the fixed frame and the pivoting frame, said thrust bearing providing for rotation of the pivoting frame relative to the fixed frame, with the concentric drive shafts passing through the center of the thrust bearing;

  for each drive shaft, a mechanism by which the drive shaft is rotated by the motor associated with the drive shaft; and

  an angle encoder mounted on the fixed frame, said angle encoder determining the angle of rotation of the pivoting frame relative to the fixed frame.
Claim 2. A mechanism as in Claim 1 for which the rotation-transfer mechanism for a drive shaft comprises a worm screw on the drive shaft and a corresponding worm wheel on the spur-gear shaft associated with the drive shaft.

Claim 3. A mechanism as in Claim 1 for which the mechanism by which a drive shaft is rotated by a motor is a direct connection between the drive shaft and the motor associated with the drive shaft.

Claim 4. A mechanism as in Claim 1 for which the mechanism by which a drive shaft is rotated by a motor comprises a gear mounted on the drive shaft and a corresponding gear mounted on the shaft of the motor associated with the drive shaft, the gear on the drive shaft being driven by the other gear.
The written opinion of the International Searching Authority indicates that independent Claim 1 lacks an inventive step but that Claims 2 and 3 as filed, which are dependent on Claim 1, do have an inventive step. This amendment combines Claim 1 with Claim 2 as filed, and cancels Claim 2 (as filed). Claim 3 as filed, which is dependent on Claim 1, but which is not affected by the change in Claim 1, is unchanged, except for the renumbering (Claim 3 as filed is Claim 2 as amended).

Statement accompanying the amendments to Claims 3 and 4 as amended:

The written opinion of the International Searching Authority objects to Claims 4 and 5 as filed as lacking clarity because of the limitation "or gearbox" in each claim. Both of these claims have been amended to change "...motor or gearbox..." to "...motor..." thereby making the claims clear.

The written opinion also objects to Claims 4 and 5 as filed, which are dependent on Claim 1, because another patent (Carmen) discloses a mechanism as in Claim 1 as filed, and teaches for mechanisms by which the drive shaft is rotated which are similar to those of Claims 4 and 5 as filed. Claim 1 as amended discloses a mechanism different from that of the other patent (Carmen), so the objection does not apply to Claims 4 and 5 as amended. Claims 4 and 5 as filed have been renumbered to Claims 3 and 4 as amended, respectively.
INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/018150

A. CLASSIFICATION OF SUBJECT MATTER

IPC (8) - A63G 31/16; B65G 23/12; 35/00; F16H 15/46; G09B 9/12 (2016.01)
CPC - A63B 2022/0271; A63F 13/08; A63G 31/16; B65G 23/12; 23/24; 35/00; G09B 9/12 (2016.02)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC (8) - A63G 31/16; B65G 23/12; 35/00; F16H 15/46; G09B 9/12 (2016.01)
CPC - A63B 2022/0271; A63F 13/08; A63G 31/16; B65G 23/12; 23/24; 35/00; G09B 9/12 (2016.02)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC - 43/29/55; 47/24/67; 60; 130; 476/61, 67
ECLA - B65G 23/12; G09B 9/12 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Orbit, Google Patents, Google Scholar, Google, YouTube
Search terms used: spur gear, helical gear, worm gear, friction, surface, bearing, encoder

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<tbody>
<tr>
<td>Y</td>
<td>US 5,980,256 A (CARMINEIN) 09 November 1999 (09.1.1999) entire document</td>
<td>1, 4, 5</td>
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<tr>
<td>Y</td>
<td>US 6,402,625 B2 (ARMSTRONG) 11 June 2002 (11.06.2002) entire document</td>
<td>1, 4, 5</td>
</tr>
<tr>
<td>Y</td>
<td>US 3,882,720 A (FABISH) 13 May 1975 (13.05.1975) entire document</td>
<td>1, 4, 5</td>
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<tr>
<td>A</td>
<td>US 9,126,121 B1 (MILAM et al) 08 September 2015 (08.09.2015) entire document</td>
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Date of mailing of the international search report
22 APR 2016

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