



US010530209B2

(12) **United States Patent**  
**Karplus et al.**

(10) **Patent No.:** **US 10,530,209 B2**  
(45) **Date of Patent:** **Jan. 7, 2020**

(54) **DEVICES AND METHODS FOR DRIVING A ROTARY PLATFORM**

(71) Applicant: **Waymo LLC**, Mountain View, CA (US)

(72) Inventors: **Paul Karplus**, Redwood City, CA (US);  
**Seth Michael LaForge**, Mountain View, CA (US)

(73) Assignee: **Waymo LLC**, Mountain View, CA (US)

(\* ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 288 days.

(21) Appl. No.: **15/337,525**

(22) Filed: **Oct. 28, 2016**

(65) **Prior Publication Data**  
US 2018/0123412 A1 May 3, 2018

(51) **Int. Cl.**  
**H02K 1/12** (2006.01)  
**H02K 1/27** (2006.01)  
(Continued)

(52) **U.S. Cl.**  
CPC ..... **H02K 1/2793** (2013.01); **H02K 1/12** (2013.01); **H02K 3/26** (2013.01); **H02K 3/28** (2013.01);  
(Continued)

(58) **Field of Classification Search**  
CPC ..... H02K 1/2793; H02K 3/26; H02K 26/00; H02K 11/215; H02K 1/12; H02K 11/30; H02K 3/28; H02K 21/24  
(Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,396,875 A \* 8/1983 Yamauchi ..... H02K 29/08  
318/400.01  
4,658,162 A \* 4/1987 Koyama ..... H01F 5/003  
310/184

(Continued)

FOREIGN PATENT DOCUMENTS

EP 1655820 A2 5/2006  
EP 2377230 A2 10/2011

(Continued)

OTHER PUBLICATIONS

Kazuya Shirahata, "Speed Control Methods of Various Types of Speed Control Motors", Oriental Motor Co., printed on Nov. 27, 2018.\*

(Continued)

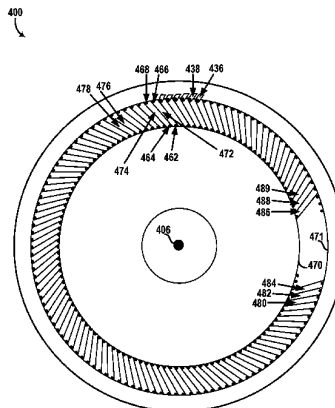
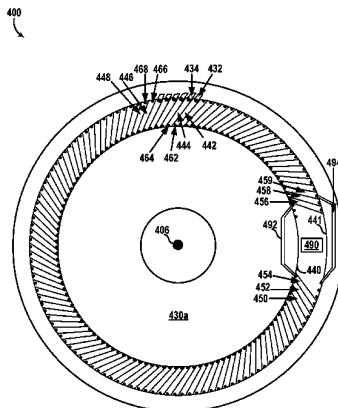
*Primary Examiner* — John K Kim

(74) *Attorney, Agent, or Firm* — McDonnell Boehnen Hulbert & Berghoff LLP

(57) **ABSTRACT**

One example device includes a rotor platform that rotates about an axis of rotation. The device also includes a ring magnet mounted to the rotor platform to provide a rotor-platform magnetic field. The device also includes a stator platform that includes a planar mounting surface. The device also includes a plurality of conductive structures disposed along the planar mounting surface. The conductive structures remain within a predetermined distance to the ring magnet in response to rotation of the rotor platform about the axis of rotation. The conductive structures are electrically coupled to define an electrically conductive path that at least partially overlaps the ring magnet. The device also includes circuitry that causes an electrical current to flow through the conductive path. The electrical current generates a stator-platform magnetic field that interacts with the rotor-platform

(Continued)



magnetic field such that the rotor platform rotates about the axis of rotation.

**16 Claims, 12 Drawing Sheets**

(51) **Int. Cl.**

**H02K 3/26** (2006.01)  
**H02K 3/28** (2006.01)  
**H02K 11/30** (2016.01)  
**H02K 11/215** (2016.01)  
**H02K 21/24** (2006.01)  
**H02K 26/00** (2006.01)

(52) **U.S. Cl.**

CPC ..... **H02K 11/215** (2016.01); **H02K 11/30** (2016.01); **H02K 26/00** (2013.01); **H02K 21/24** (2013.01)

(58) **Field of Classification Search**

USPC ..... 310/68 B, 156.32, 156.38, 156.44  
 See application file for complete search history.

(56)

**References Cited**

U.S. PATENT DOCUMENTS

4,733,115 A 3/1988 Barone et al.  
 5,498,919 A \* 3/1996 Bahn ..... H02K 23/54  
 310/156.05  
 5,898,301 A \* 4/1999 La Croix ..... G01D 5/2457  
 324/207.22  
 7,112,910 B2 \* 9/2006 Lopatinsky ..... H02K 1/2793  
 310/156.32  
 2003/0020353 A1 \* 1/2003 Lopatinsky ..... H02K 1/2793  
 310/208  
 2004/0189130 A1 9/2004 Hovanky et al.  
 2004/0245957 A1 \* 12/2004 Shibata ..... G11B 19/28  
 318/560  
 2006/0055265 A1 3/2006 Zalusky  
 2008/0018330 A1 \* 1/2008 Legrand ..... G01D 5/24438  
 324/207.25

2008/0042515 A1 \* 2/2008 Butterfield ..... H02K 3/26  
 310/268  
 2008/0252285 A1 10/2008 Passwater et al.  
 2009/0195106 A1 \* 8/2009 Iki ..... H02K 3/26  
 310/208  
 2010/0067085 A1 3/2010 Bernstein et al.  
 2012/0043862 A1 \* 2/2012 Furukawa ..... H02K 1/278  
 310/68 B  
 2012/0080974 A1 \* 4/2012 Tanimoto ..... H02K 3/26  
 310/208  
 2012/0126927 A1 \* 5/2012 Iwaya ..... H02K 3/26  
 336/200  
 2012/0133474 A1 \* 5/2012 Iwaya ..... H02K 3/26  
 336/200  
 2013/0009508 A1 \* 1/2013 Takamatsu ..... H02K 1/02  
 310/156.35  
 2013/0026888 A1 \* 1/2013 Migita ..... H02K 29/08  
 310/68 B  
 2013/0307367 A1 \* 11/2013 Yoshida ..... H02K 3/26  
 310/198  
 2015/0349609 A1 \* 12/2015 Tremelling ..... F04D 19/002  
 310/63  
 2016/0197573 A1 \* 7/2016 Iwata ..... H02P 27/04  
 318/400.26  
 2017/0025931 A1 \* 1/2017 Endo ..... H02K 29/08  
 2018/0123412 A1 \* 5/2018 Karplus ..... H02K 11/215

FOREIGN PATENT DOCUMENTS

GB 2485185 A 5/2012  
 JP S59139850 A 8/1984  
 JP S60125143 A 7/1985  
 JP S61210849 A 9/1986  
 JP 2012120423 A 6/2012  
 WO 03003547 A1 1/2003  
 WO 2004073365 A2 8/2004  
 WO 2011006515 A1 1/2011

OTHER PUBLICATIONS

International Search Report and Written Opinion of corresponding International Application No. PCT/US2017/053515 (dated Dec. 12, 2017).

\* cited by examiner

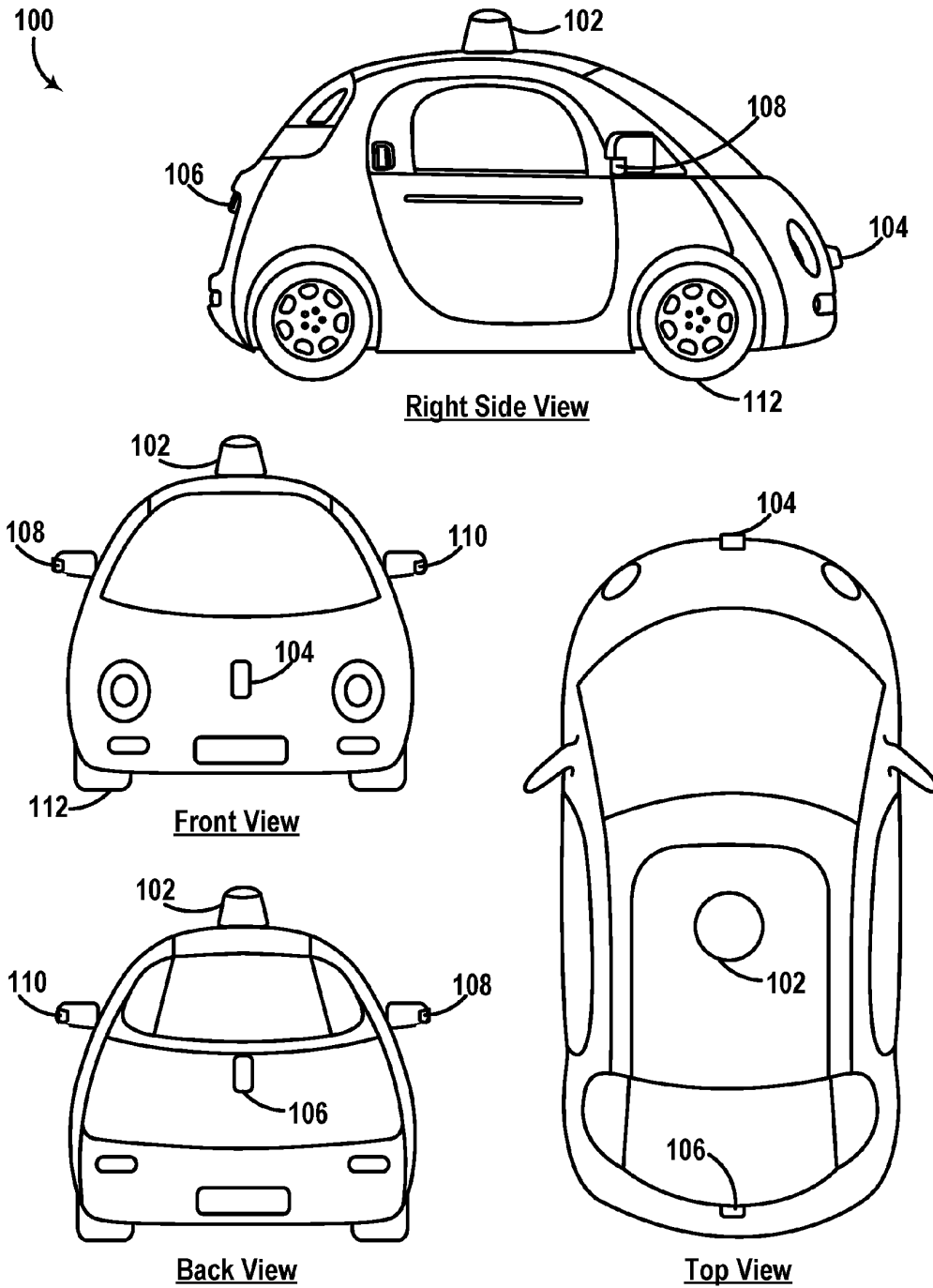


FIG. 1

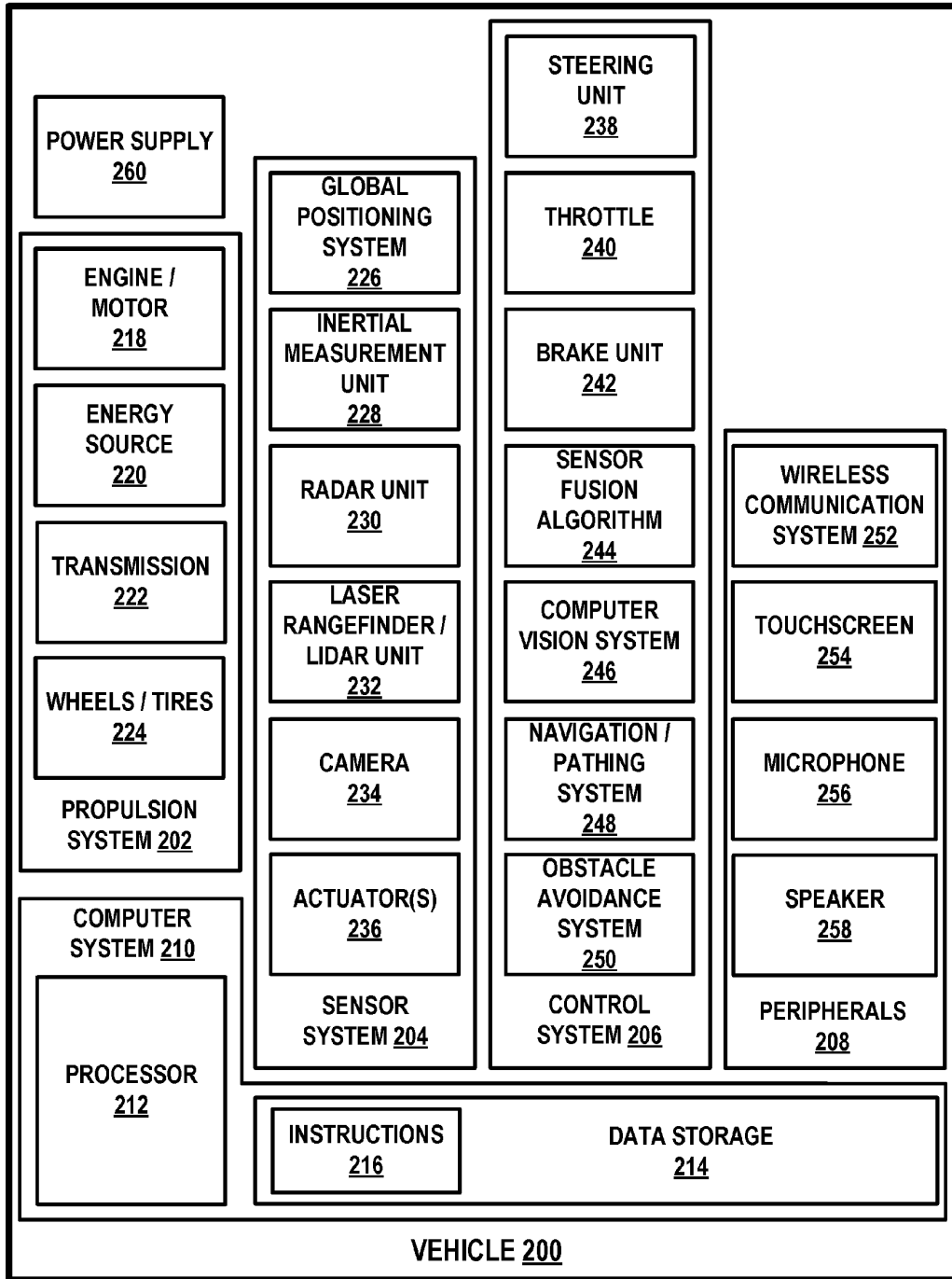


FIG. 2

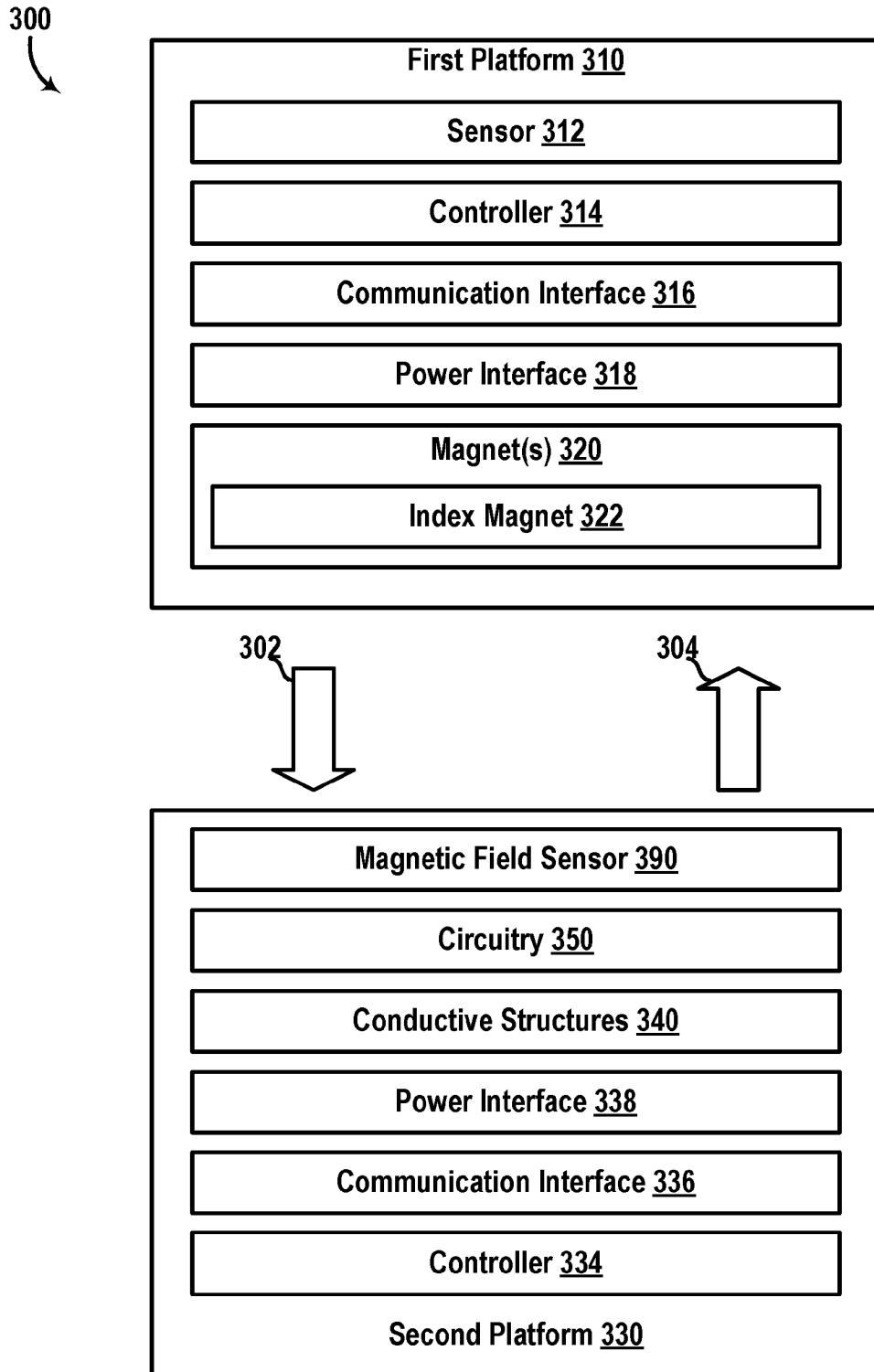


FIG. 3

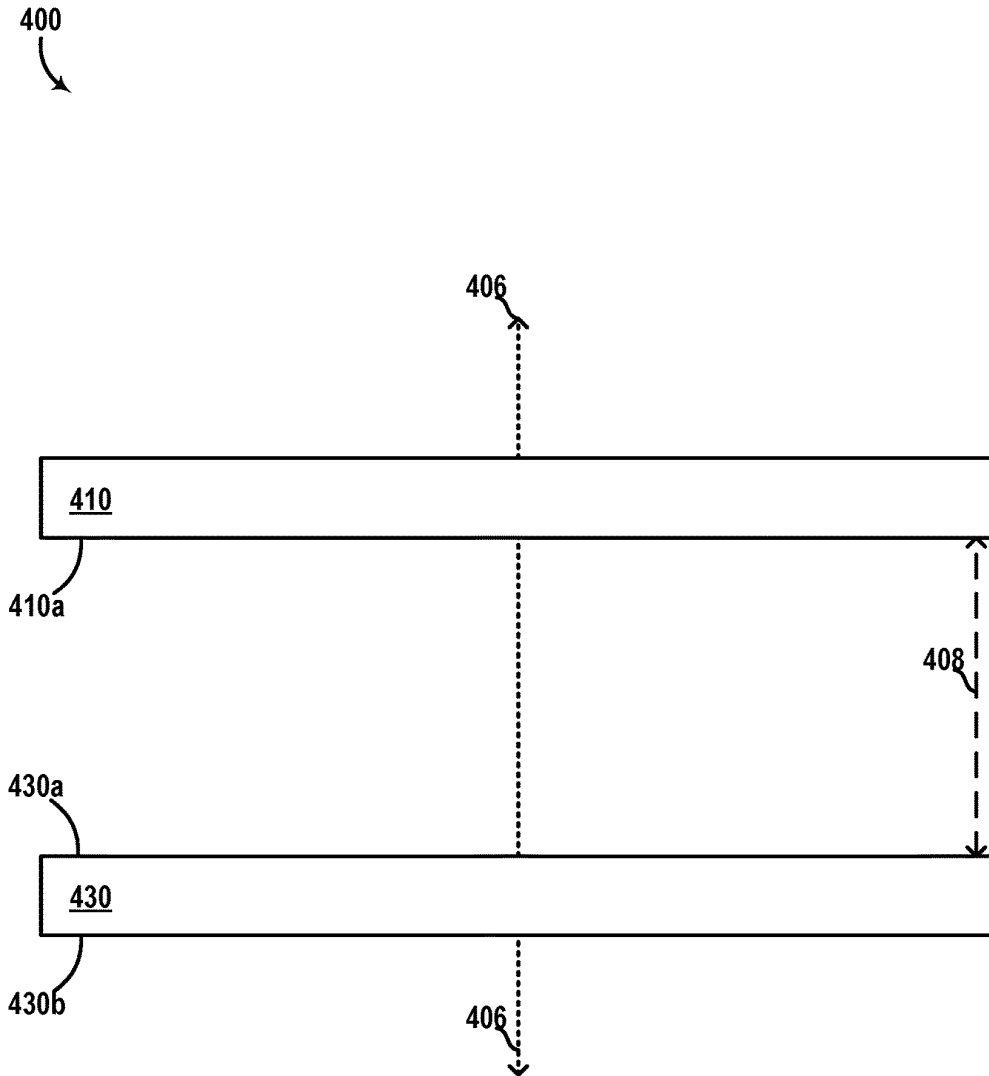


FIG. 4A

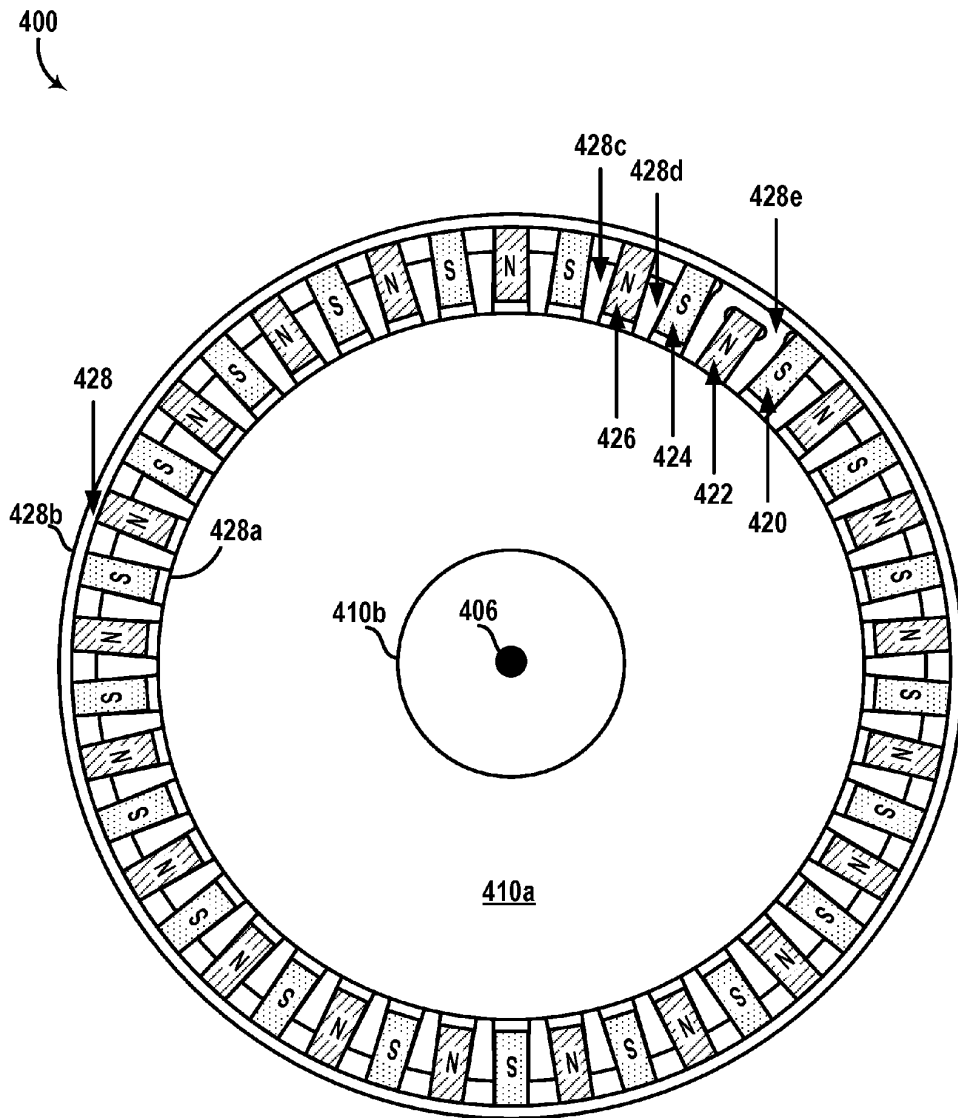


FIG. 4B

400  
↙

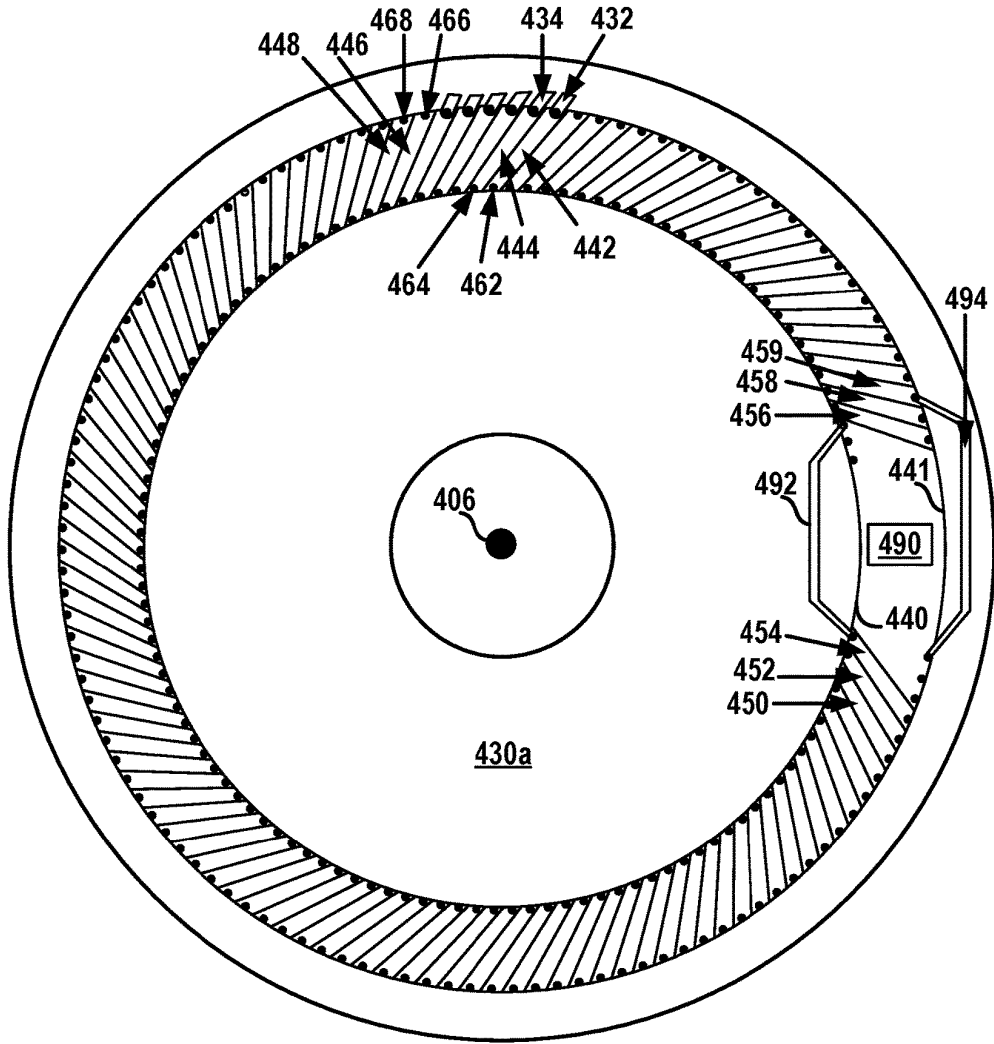


FIG. 4C

400

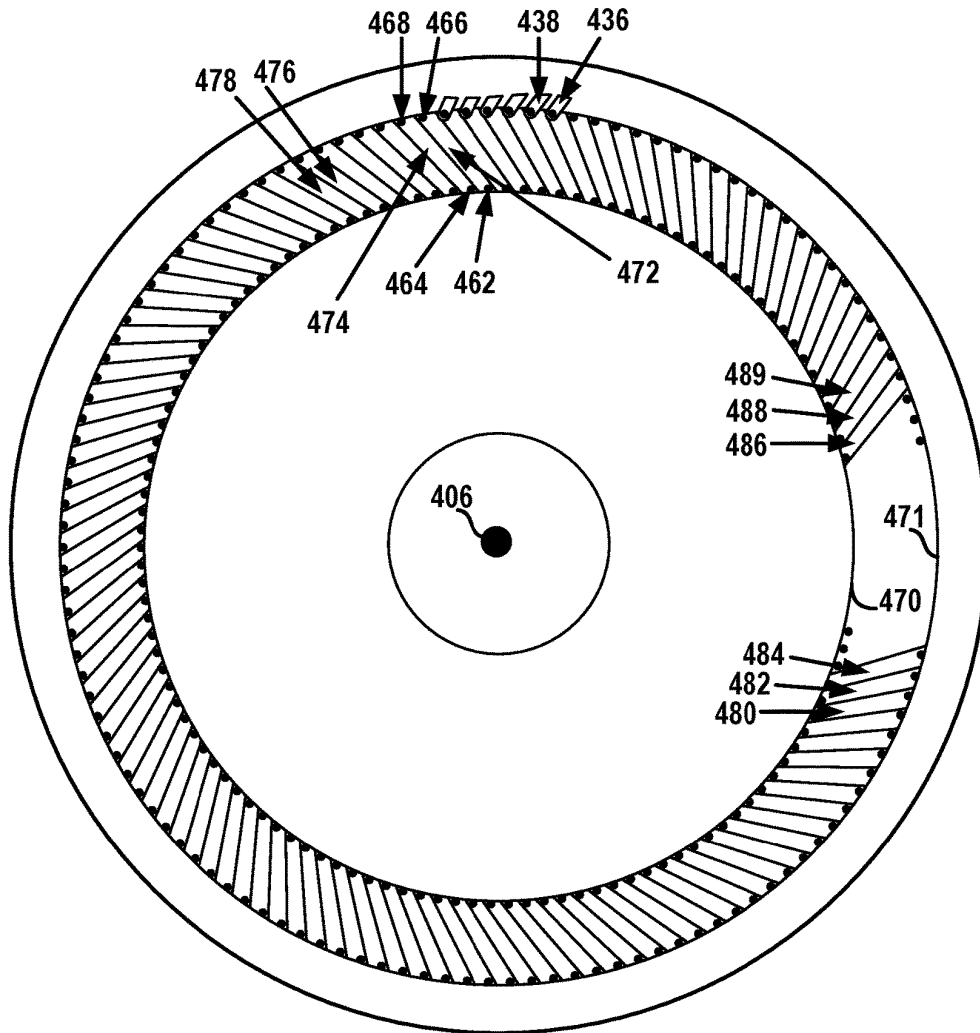


FIG. 4D

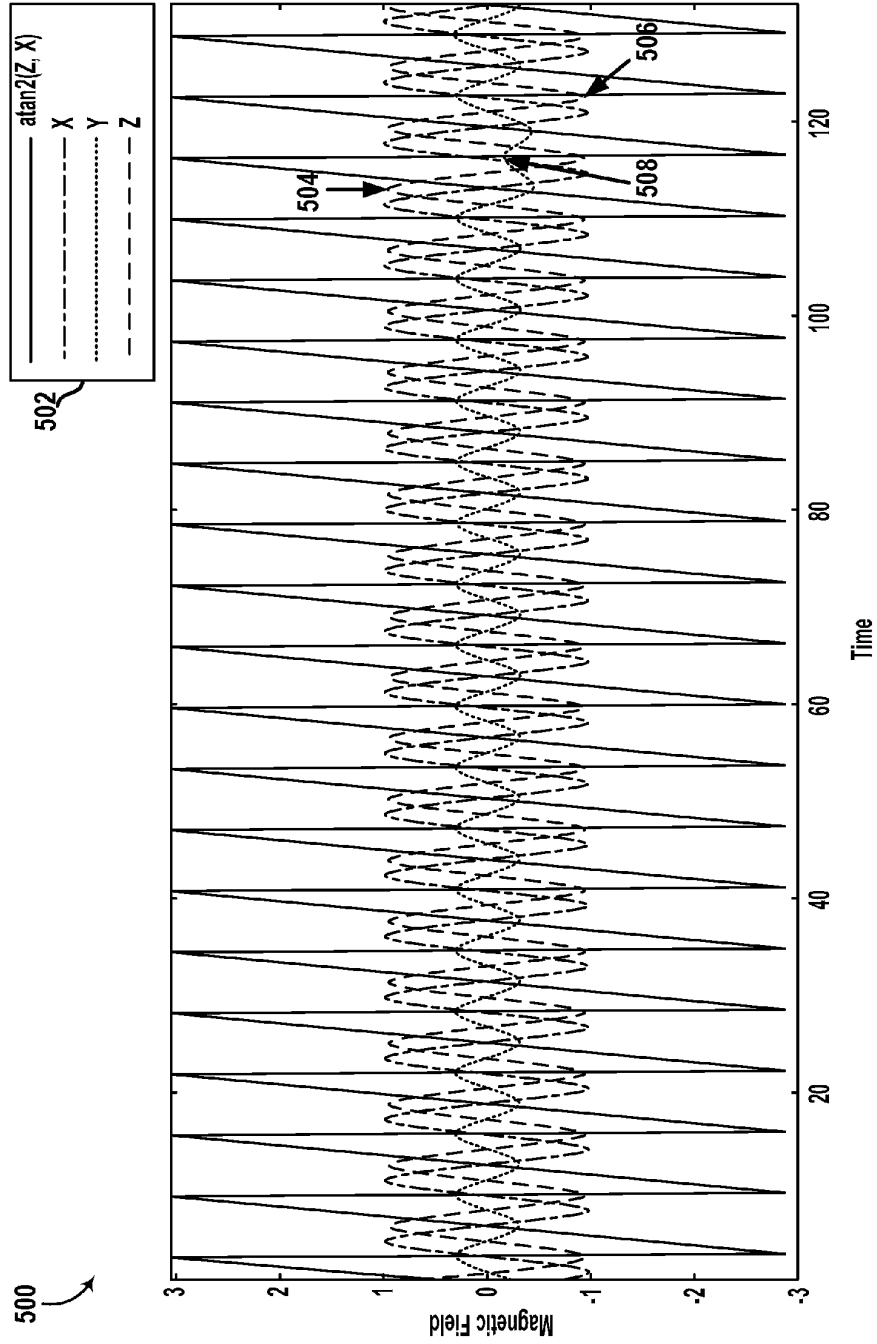


FIG. 5

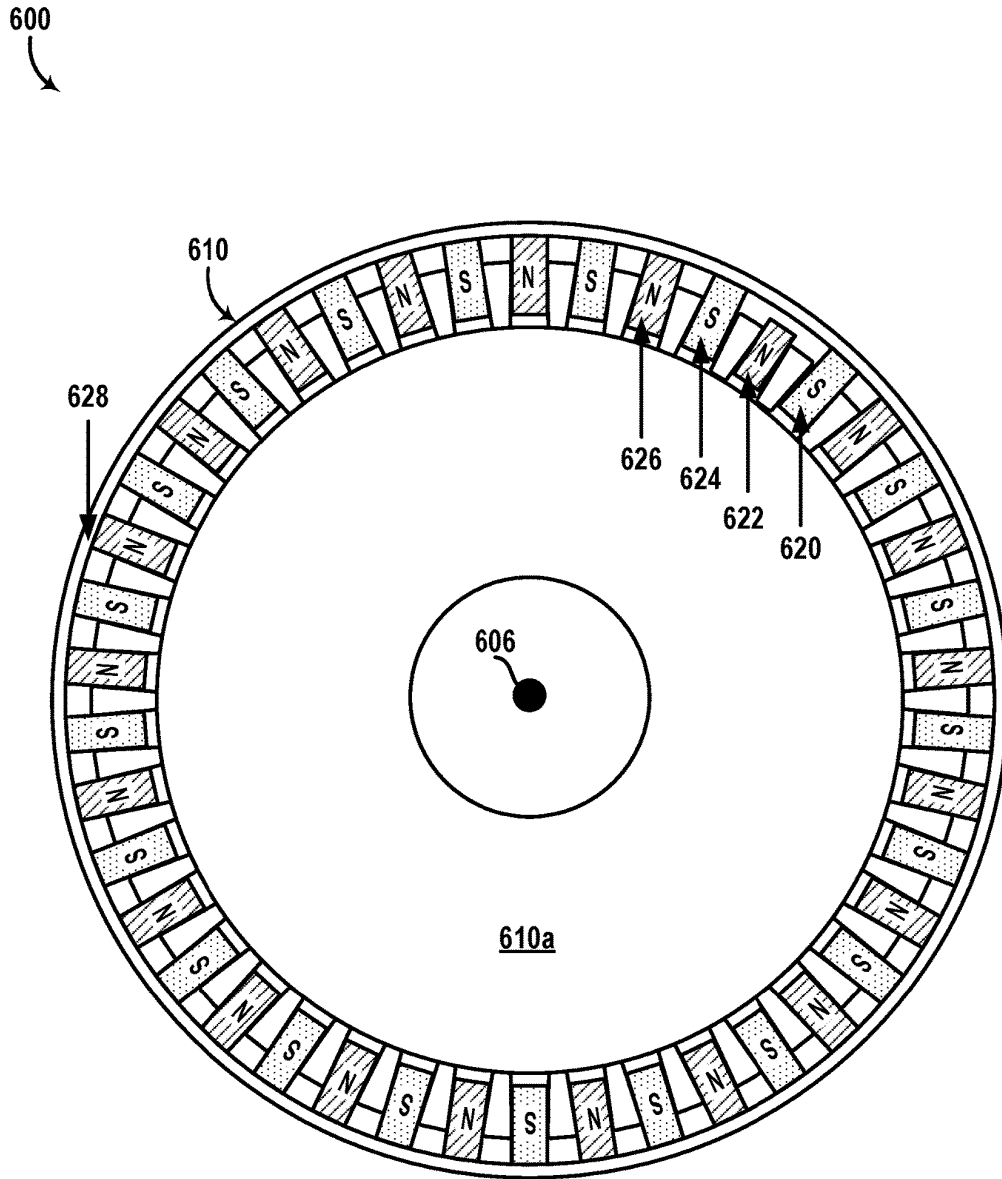


FIG. 6

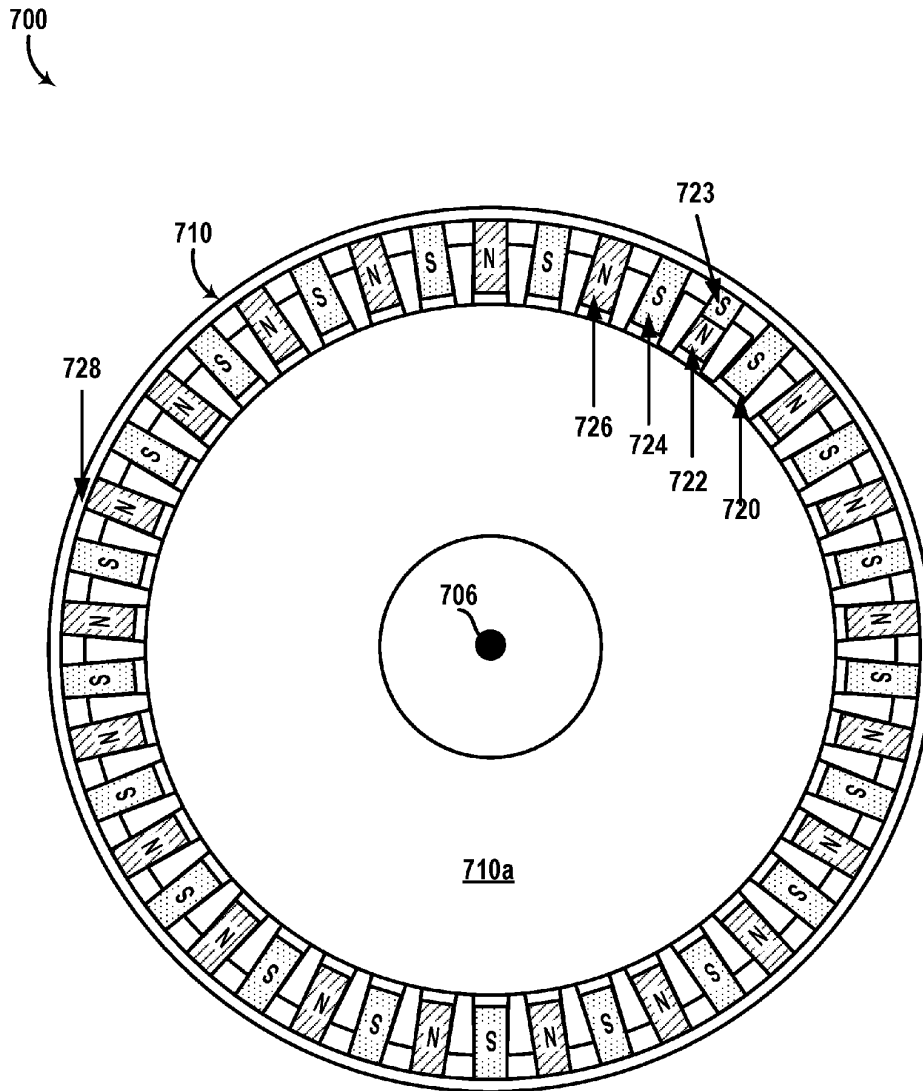


FIG. 7

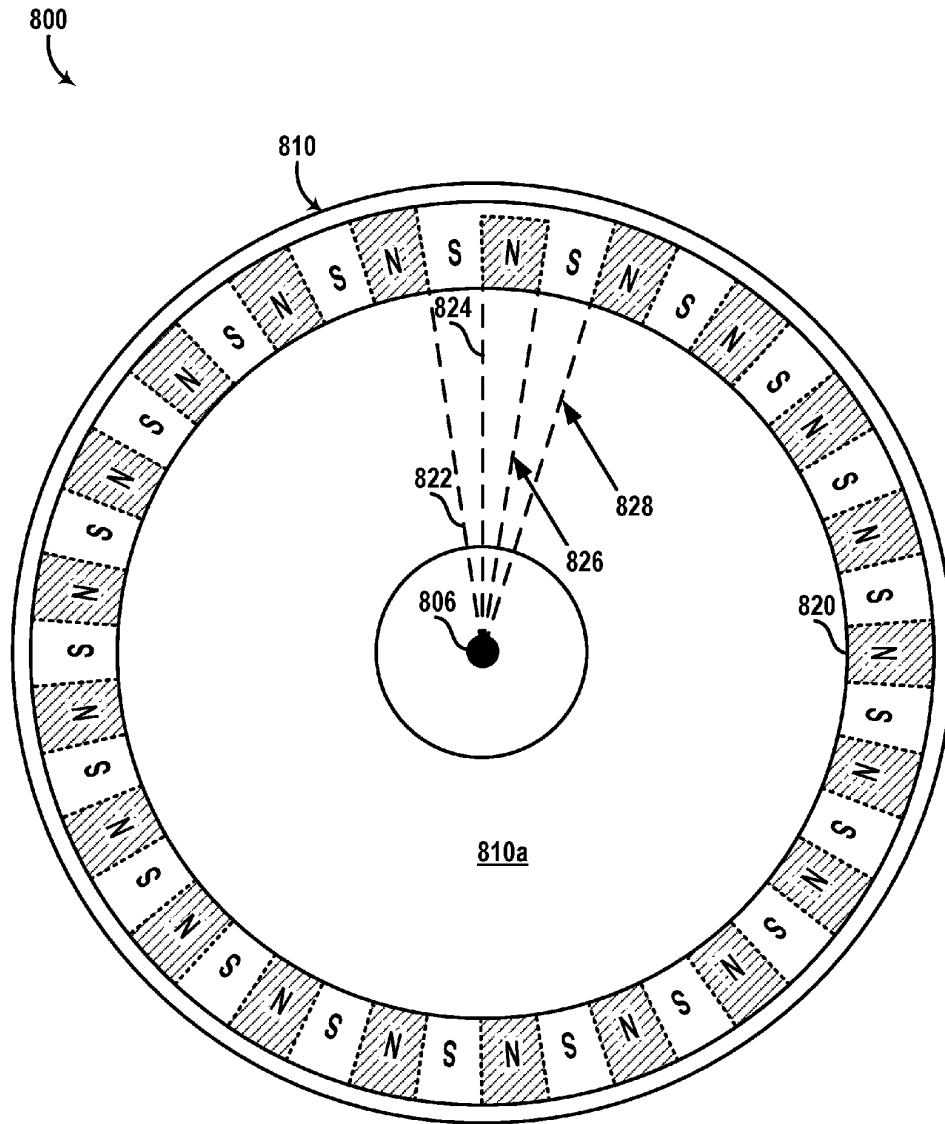


FIG. 8

900

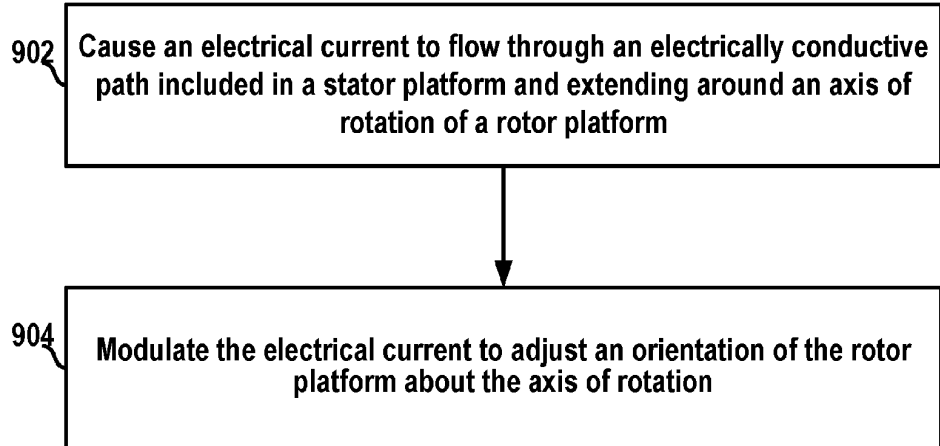


FIG. 9

1

## DEVICES AND METHODS FOR DRIVING A ROTARY PLATFORM

### BACKGROUND

Unless otherwise indicated herein, the materials described in this section are not prior art to the claims in this application and are not admitted to be prior art by inclusion in this section.

Rotary joint devices are often used for transmission of power and/or electrical signals between one structure and another structure in an electromechanical system that operates by causing a relative rotation between the two structures (e.g., stator and rotor). Example systems that employ rotary joint devices include remote sensing systems (e.g., RADARs, LIDARs, etc.) and robotic systems (e.g., for directing microphones, speakers, robotic components, etc.), among others.

### SUMMARY

In one example, a device includes a first platform having a first side, and a second platform having a second side that at least partially overlaps the first side of the first platform. The first side remains within a predetermined distance to the second side in response to rotation of the first platform about an axis of rotation of the first platform. The device also includes a plurality of magnets mounted to the first platform in a circular arrangement around the axis of rotation. The plurality of magnets provides a first-platform magnetic field. The device also includes a plurality of conductive structures included in the second platform in a substantially coplanar arrangement around the axis of rotation. The plurality of conductive structures is defines an electrically conductive path. The device also includes circuitry that causes an electrical current to flow through the electrically conductive path. The electrical current generates a second-platform magnetic field that interacts with the first-platform magnetic field such that the first platform rotates about the axis of rotation.

In another example, a method for rotating a first platform of a device relative to a second platform of the device and about an axis of rotation of the first platform is disclosed. The first platform remains within a predetermined distance to the second platform in response to rotation of the first platform about the axis of rotation. The method involves causing an electrical current to flow through an electrically conductive path included in the second platform and extending around the axis of rotation of the first platform. The electrically conductive path is defined by a plurality of conductive structures in a substantially coplanar arrangement. The electrical current generates a second-platform magnetic field that interacts with a first-platform magnetic field such that the first platform rotates about the axis of rotation. The method also involves modulating the electrical current to adjust an orientation of the first platform about the axis of rotation to achieve a target orientation.

In yet another example, a device includes a rotor platform that rotates about an axis of rotation of the rotor platform. The device also includes a ring magnet mounted to the rotor platform to provide a rotor-platform magnetic field. The ring magnet is concentric to the axis of rotation. The device also includes a stator platform that includes a planar mounting surface. The device also includes a plurality of conductive structures disposed along the planar mounting surface. The plurality of conductive structures remains within a predetermined distance to the ring magnet in response to rotation

2

of the rotor platform about the axis of rotation. The plurality of conductive structures define an electrically conductive path that at least partially overlaps the ring magnet. The device also includes circuitry that causes an electrical current to flow through the electrically conductive path. The electrical current generates a stator-platform magnetic field that interacts with the rotor-platform magnetic field to induce a force that causes the rotor platform to rotate about the axis of rotation.

In still another example, a system for rotating a first platform of a device relative to a second platform of the device and about an axis of rotation of the first platform is disclosed. The first platform remains within a predetermined distance to the second platform in response to rotation of the first platform about the axis of rotation. The system comprises means for causing an electrical current to flow through an electrically conductive path included in the second platform and extending around the axis of rotation of the first platform. The electrically conductive path is defined by a plurality of conductive structures in a substantially coplanar arrangement. The electrical current generates a second-platform magnetic field that interacts with a first-platform magnetic field such that the first platform rotates about the axis of rotation. The system also comprises means for modulating the electrical current to adjust an orientation of the first platform about the axis of rotation to achieve a target orientation.

These as well as other aspects, advantages, and alternatives, will become apparent to those of ordinary skill in the art by reading the following detailed description, with reference where appropriate to the accompanying figures.

### BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 illustrates a vehicle, according to an example embodiment.

FIG. 2 is a simplified block diagram of a vehicle, according to an example embodiment.

FIG. 3 is a simplified block diagram of a device that includes a rotary joint, according to an example embodiment.

FIG. 4A illustrates a side view of a device that includes a rotary joint, according to an example embodiment.

FIG. 4B illustrates a cross-section view of the device in FIG. 4A.

FIG. 4C illustrates another cross-section view of the device in FIG. 4A.

FIG. 4D illustrates yet another cross-section view of the device in FIG. 4A.

FIG. 5 is a conceptual illustration of the relationship between orientations of a rotor platform and outputs from a magnetic field sensor, according to an example embodiment.

FIG. 6 is a cross-section view of another device that includes a rotary joint, according to an example embodiment.

FIG. 7 is a cross-section view of yet another device that includes a rotary joint, according to an example embodiment.

FIG. 8 is a cross-section view of still another device that includes a rotary joint, according to an example embodiment.

FIG. 9 is a flowchart of a method, according to an example embodiment.

### DETAILED DESCRIPTION

The following detailed description describes various features and functions of the disclosed implementations with

reference to the accompanying figures. In the figures, similar symbols identify similar components, unless context dictates otherwise. The illustrative implementations described herein are not meant to be limiting. It may be readily understood by those skilled in the art that certain aspects of the disclosed implementations can be arranged and combined in a wide variety of different configurations.

#### 1. Overview

Within examples, a rotary joint device includes two platforms arranged such that a first side of a first platform (one of the stator and rotor platforms) remains within a predetermined distance to a second side of a second platform (the other of the stator and rotor platforms) in response to a relative rotation between the two platforms. In one example, the two platforms may include circularly shaped disks arranged coaxially to maintain an overlap between the two respective sides (separated by the predetermined distance) in response to rotation of any of the two platforms about a common axis of the two platforms.

In some implementations, the device also includes a plurality of magnets mounted to the first platform in a substantially circular arrangement about an axis of rotation of the first platform. In one example, the plurality of magnets can be implemented as permanent magnets (e.g., ferrimagnets, etc.) that are arranged along a periphery of a circularly shaped disk on a side of the disk (e.g., the first side) that is facing the second side of the second platform. Further, in this example, each magnet may have a magnetic pole facing the second platform that has an opposite magnetic polarity compared to an adjacent magnet in the circular arrangement. With this arrangement, for instance, magnetic field components may extend between the adjacent magnets to form a combined first-platform magnetic field. In another example, the plurality of magnets can be implemented as a printed ring magnet that is magnetized to have alternating magnetic polarities between adjacent sectors of the ring magnet.

In some implementations, the device also includes a plurality of conductive structures included in the second platform in a substantially coplanar arrangement around the axis of rotation. For example, the conductive structures can be implemented as patterned traces or tracks disposed in a first layer of a printed circuit board (PCB). Further, in some instances, the second platform also includes a second plurality of conductive structures that are also coplanar (e.g., disposed in a second layer of the PCB). The conductive structures in the first layer and the second layer can be electrically coupled (e.g., through PCB "vias," etc.) to form a coil extending around the axis of rotation to at least partially overlap one or more of the plurality of magnets.

In some implementations, the device also includes circuitry that causes an electrical current to flow through a conductive path which includes one or more of the conductive structures. The circuitry, for example, may include any combination of power sources, voltage regulators, current amplifiers, resistors, capacitors, inductors, controllers, wiring, among other examples. As a result, for instance, the electrical current may cause the conductive path (e.g., coil) to generate a second-platform magnetic field that interacts with the first-platform magnetic field associated with the plurality of magnets. Further, the interaction between the magnetic fields may induce a force (and/or torque) that causes a rotation of the first platform relative to the second platform and about the axis of rotation.

With this arrangement, in some instances, the device may allow controlling rotation of the first platform (e.g., rotor) by way of a PCB motor incorporated in the two platforms. Thus, instead of an implementation where a physically

separate actuator is coupled to the first platform, this implementation may be more suitable for small rotary joint configurations by physically implementing the actuator as components included and/or mounted to the rotor and stator platforms for a more compact and/or efficient use of space in the rotary joint device.

In some implementations, the plurality of conductive structures can be arranged to define multiple separate conductive paths extending around the axis of rotation. For example, a first current-carrying coil extending around the axis of rotation can be formed by electrically coupling a subset of the conductive structures. Further, a second coil can be interleaved with the first coil by electrically coupling another subset of the conductive structures. As a result, in this example, the area of the second platform overlapping the plurality of magnets in the first platform can be densely packed with conductive material (i.e., multiple coils or windings) to efficiently allow the device to selectively adjust the number of windings or coils for more precise control of the induced force or torque acting on the first platform. Thus, in some implementations, the plurality of conductive structures may include a plurality of spaced-apart conductive structures that are spaced apart by a substantially uniform distance. Additionally, in some instances, adjacent structures of the plurality of spaced-apart structures may be respectively included in different electrically conductive paths or coils.

Further, in some implementations, the device may include a gap between two particular adjacent conductive structures in the circular arrangement of conductive structures in the second platform. For example, the two particular structures can be spaced apart by a distance that is greater than the substantially uniform distance between other structures of the plurality of spaced-apart structures. In these implementations, the device also includes a magnetic field sensor (e.g., Hall effect sensor, etc.) disposed in the first-platform magnetic field and between the two particular structures to provide an output indicative of a characteristic of the first-platform magnetic field at a position of the magnetic field sensor. For example, in a PCB implementation, the magnetic field sensor and the two particular conductive structures can be disposed along the same side or layer of the PCB. Alternatively, for example, the two particular conductive structures can be included in a first layer of the PCB (e.g., along a side of the PCB facing the first platform), and the magnetic field sensor can be mounted to a second layer of the PCB (e.g., along a side of the PCB opposite to the side facing the first platform). Other examples are possible as well.

Through this process, the device can then determine an orientation of the first platform about the axis of rotation based on the output from the magnetic field sensor. For example, the sensor can measure an angle of the magnetic field between two adjacent magnets that are at least partially overlapping the gap or cut-out region where the sensor is located. The device can then process and keep track of the angle measurements from the sensor to determine the orientation of the first platform about the axis of rotation. Further, the gap between the two particular structures may allow for reducing interference between the magnetic field associated with the two adjacent magnets and the magnetic field associated with the electrical current flowing through the conductive structures in the second platform. As a result, for instance, the reliability and accuracy of sensor measurements can be improved.

With this arrangement, for example, the device can combine the functionality of an actuator that rotates the first

platform and a magnetic encoder that uses the same plurality of magnets used by the actuator to measure and/or keep track of the orientation of the first platform. By doing so, for instance, the size, assembly costs, and maintenance costs of the device can be reduced relative to a device that includes separate components (e.g., magnets, etc.) for an actuator and a magnetic encoder (or other type of encoder).

Additionally, in some implementations, the plurality of magnets in the first platform may include an index magnet configured to have a characteristic that differs from a corresponding characteristic of other magnets of the plurality of magnets. In one example, the characteristic may relate to a positional or rotational displacement of the index magnet relative to the circular arrangement of the plurality of magnets. In other examples, the characteristic may relate to any combination of magnetization strength, magnetization direction, and/or magnetization pattern, among other examples.

In some examples, the first-platform magnetic field may have an irregularity in the region of the first-platform magnetic field associated with the index magnet (e.g., portion of the first-platform magnetic field extending between the index magnet and magnets adjacent to the index magnet). Additionally, the output of the magnetic field sensor can indicate this irregularity, and the device can use this indication as a basis for detecting that the first platform is at an “index” orientation or position about the axis of rotation. As a result, the device can determine an absolute position or orientation of the first platform about the axis of rotation by keeping track of the extent and direction of rotation of the first platform after detecting the index orientation or position of the first platform.

Other example arrangements, configurations, functionalities, and operations are possible as well and are described in greater detail within exemplary implementations herein.

## II. Example Electromechanical Systems and Devices

Systems and devices in which example embodiments may be implemented will now be described in greater detail. In general, the embodiments disclosed herein can be used with any electromechanical system that includes a moveable component. An example system can provide for transmission of power and/or signals between the moveable component and other parts of the system. Illustrative embodiments described herein include vehicles that have moveable components such as sensors and wheels that communicate with other components of the vehicle and/or with one another. However, an example electromechanical system may also be implemented in or take the form of other devices, such as sensor platforms (e.g., RADAR platforms, LIDAR platforms, direction sensing platforms, etc.), robotic devices, industrial systems (e.g., assembly lines, etc.), medical devices (e.g., medical imaging devices, etc.), or mobile communication systems, among others. Further, it is noted that the term “vehicle” is broadly construed herein to cover any moving object including, for instance, an aerial vehicle, watercraft, spacecraft, a car, a truck, a van, a semi-trailer truck, a motorcycle, a golf cart, an off-road vehicle, a warehouse transport vehicle, a farm vehicle, or a carrier that rides on a track (e.g., roller coaster, trolley, tram, train car, etc.), among others.

FIG. 1 illustrates a vehicle 100, according to an example embodiment. In particular, FIG. 1 shows a Right Side View, Front View, Back View, and Top View of the vehicle 100. Although vehicle 100 is illustrated in FIG. 1 as a car, as noted above, other types of vehicles are possible as well. Furthermore, although vehicle 100 can be configured to operate autonomously, the embodiments described herein

are also applicable to vehicles that are not configured to operate autonomously or that are configured to operate semi-autonomously. Thus, vehicle 100 is not meant to be limiting. As shown, vehicle 100 includes five sensor units 102, 104, 106, 108, and 110, and four wheels, exemplified by wheel 112.

In some embodiments, sensor units 102-110 may include any combination of sensors, such as global positioning system sensors, inertial measurement units, radio detection and ranging (RADAR) units, cameras, laser rangefinders, light detection and ranging (LIDAR) units, or acoustic sensors, among other possibilities.

As shown, sensor unit 102 is mounted to a top side of the vehicle 100 opposite to a bottom side of the vehicle 100 where the wheel 112 is mounted. Further, sensor units 104-110 are respectively mounted to respective sides of vehicle 100 other than the top side. As shown, sensor unit 104 is positioned at a front side of vehicle 100, sensor 106 is positioned at a back side of vehicle 100, the sensor unit 108 is positioned at a right side of vehicle 100, and sensor unit 110 is positioned at a left side of vehicle 100.

Although sensor units 102-110 are shown to be mounted in particular locations on vehicle 100, in some embodiments, sensor units 102-110 can be mounted in other locations, either inside or outside vehicle 100. For example, although sensor unit 108 as shown is mounted to a rear-view mirror of vehicle 100, sensor unit 108 may alternatively be positioned in another location along the right side of vehicle 100. Further, while five sensor units are shown, in some embodiments more or fewer sensor units may be included in vehicle 100. However, for the sake of example, sensor units 102-110 are positioned as shown.

In some embodiments, one or more of sensor units 102-110 may include one or more movable mounts on which the sensors can be movably mounted. A movable mount may include, for example, a rotating platform. Alternatively or additionally, a movable mount may include a tilting platform. Sensors mounted on a tilting platform could be tilted within a given range of angles and/or azimuths, for example. A movable mount may take other forms as well.

In some embodiments, one or more of sensor units 102-110 may include one or more actuators configured to adjust a position and/or orientation of sensors in the sensor unit by moving the sensors and/or movable mounts. Example actuators include motors, pneumatic actuators, hydraulic pistons, relays, solenoids, and piezoelectric actuators, among others.

As shown, vehicle 100 includes one or more wheels such as wheel 112 that are configured to rotate to cause the vehicle to travel along a driving surface. In some embodiments, wheel 112 may include at least one tire coupled to a rim of wheel 112. To this end, wheel 112 may include any combination of metal and rubber, or a combination of other materials. Vehicle 100 may include one or more other components in addition to or instead of those shown.

FIG. 2 is a simplified block diagram of a vehicle 200, according to an example embodiment. Vehicle 200 may be similar to vehicle 100, for example. As shown, vehicle 200 includes a propulsion system 202, a sensor system 204, a control system 206, peripherals 208, and a computer system 210. In other embodiments, vehicle 200 may include more, fewer, or different systems, and each system may include more, fewer, or different components. Further, the systems and components shown may be combined or divided in any number of ways.

Propulsion system 202 may be configured to provide powered motion for the vehicle 200. As shown, propulsion

system **202** includes an engine/motor **218**, an energy source **220**, a transmission **222**, and wheels/tires **224**.

Engine/motor **218** may be or include any combination of an internal combustion engine, an electric motor, a steam engine, and a Stirling engine. Other motors and engines are possible as well. In some embodiments, propulsion system **202** may include multiple types of engines and/or motors. For instance, a gas-electric hybrid car may include a gasoline engine and an electric motor. Other examples are possible.

Energy source **220** may be a source of energy that powers the engine/motor **218** in full or in part. That is, engine/motor **218** may be configured to convert energy source **220** into mechanical energy. Examples of energy sources **220** include gasoline, diesel, propane, other compressed gas-based fuels, ethanol, solar panels, batteries, and other sources of electrical power. Energy source(s) **220** may additionally or alternatively include any combination of fuel tanks, batteries, capacitors, and/or flywheels. In some embodiments, energy source **220** may provide energy for other systems of vehicle **200** as well.

Transmission **222** may be configured to transmit mechanical power from engine/motor **218** to wheels/tires **224**. To this end, transmission **222** may include a gearbox, clutch, differential, drive shafts, and/or other elements. In embodiments where transmission **222** includes drive shafts, the drive shafts may include one or more axles that are configured to be coupled to wheels/tires **224**.

Wheels/tires **224** of vehicle **200** may be configured in various formats, including a unicycle, bicycle/motorcycle, tricycle, or car/truck four-wheel format. Other wheel/tire formats are possible as well, such as those including six or more wheels. In any case, wheels/tires **224** may be configured to rotate differentially with respect to other wheels/tires **224**. In some embodiments, wheels/tires **224** may include at least one wheel that is fixedly attached to transmission **222** and at least one tire coupled to a rim of the wheel that could make contact with a driving surface. Wheels/tires **224** may include any combination of metal and rubber, or combination of other materials. Propulsion system **202** may additionally or alternatively include components other than those shown.

Sensor system **204** may include any number of sensors configured to sense information about vehicle **200** and/or an environment in which vehicle **200** is located, as well as one or more actuators **236** configured to modify a position and/or orientation of the sensors. As shown, sensor system **204** includes a Global Positioning System (GPS) **226**, an inertial measurement unit (IMU) **228**, a RADAR unit **230**, a laser rangefinder and/or LIDAR unit **232**, and a camera **234**. Sensor system **204** may include additional sensors as well, including, for example, sensors that monitor internal systems of vehicle **200** (e.g., an O<sub>2</sub> monitor, a fuel gauge, an engine oil temperature, etc.). Other sensors are possible as well. In some examples, sensor system **204** may be implemented as multiple sensor units each mounted to the vehicle in a respective position (e.g., top side, bottom side, front side, back side, right side, left side, etc.).

GPS **226** may include any sensor (e.g., location sensor) configured to estimate a geographic location of vehicle **200**. To this end, for example, GPS **226** may include a transceiver configured to estimate a position of vehicle **200** with respect to the Earth. IMU **228** may include any combination of direction sensors configured to sense position and orientation changes of the vehicle **200** based on inertial acceleration. Example IMU sensors include accelerometers, gyroscopes, other direction sensors, etc. RADAR unit **230** may

include any sensor configured to sense objects in an environment in which vehicle **200** is located using radio signals. In some embodiments, in addition to sensing the objects, RADAR unit **230** may be configured to sense the speed and/or heading of the objects.

Laser rangefinder or LIDAR unit **232** may include any sensor configured to sense objects in the environment in which vehicle **200** is located using light. In particular, laser rangefinder or LIDAR unit **232** may include one or more light sources configured to emit one or more beams of light and a detector configured to detect reflections of the one or more beams of light. Laser rangefinder or LIDAR **232** may be configured to operate in a coherent (e.g., using heterodyne detection) or an incoherent detection mode. In some examples, LIDAR unit **232** may include multiple LIDARs, with each LIDAR having a particular position and/or configuration suitable for scanning a particular region of an environment around vehicle **200**.

Camera **234** may include any camera (e.g., still camera, video camera, etc.) that can capture images of an environment of vehicle **200**. Actuator(s) **236** may include any type of actuator configured to adjust a position, orientation, and/or pointing direction of one or more of the sensors of system **204**. Example actuators include motors, pneumatic actuators, hydraulic pistons, relays, solenoids, and piezoelectric actuators, among other examples. Sensor system **204** may additionally or alternatively include components other than those shown.

Control system **206** may be configured to control operation of vehicle **200** and/or components thereof. To this end, control system **206** may include a steering unit **238**, a throttle **240**, a brake unit **242**, a sensor fusion algorithm **244**, a computer vision system **246**, a navigation or pathing system **248**, and an obstacle avoidance system **250**.

Steering unit **238** may be any combination of mechanisms configured to adjust the heading of vehicle **200**. Throttle **240** may be any combination of mechanisms configured to control the operating speed of engine/motor **218** and, in turn, the speed of vehicle **200**. Brake unit **242** may be any combination of mechanisms configured to decelerate vehicle **200**. For example, brake unit **242** may use friction to slow wheels/tires **224**. In some examples, brake unit **242** may also convert kinetic energy of wheels/tires **224** to an electric current.

Sensor fusion algorithm **244** may be an algorithm (or a computer program product storing an algorithm) configured to accept data from sensor system **204** as an input. The data may include, for example, data representing information sensed at the sensors of sensor system **204**. Sensor fusion algorithm **244** may include, for example, a Kalman filter, a Bayesian network, an algorithm for some of the functions of the methods herein, or any other algorithm. Sensor fusion algorithm **244** may further be configured to provide various assessments based on the data from sensor system **204**, including, for example, evaluations of individual objects and/or features in the environment in which vehicle **100** is located, evaluations of particular situations, and/or evaluations of possible impacts based on particular situations.

Computer vision system **246** may be any system configured to process and analyze images captured by camera **234** in order to identify objects and/or features in the environment in which vehicle **200** is located, including, for example, traffic signals and obstacles. To this end, computer vision system **246** may use an object recognition algorithm, a Structure from Motion (SFM) algorithm, video tracking, or other computer vision techniques. In some embodiments,

computer vision system **246** may additionally be configured to map the environment, track objects, estimate the speed of objects, etc.

Navigation and pathing system **248** may be any system configured to determine a driving path for vehicle **200**. Navigation and pathing system **248** may additionally be configured to update the driving path dynamically while vehicle **200** is in operation. In some embodiments, navigation and pathing system **248** may be configured to incorporate data from sensor fusion algorithm **244**, GPS **226**, LIDAR unit **232**, and/or one or more predetermined maps of the environment of vehicle **200**, so as to determine a driving path for vehicle **200**. Obstacle avoidance system **250** may be any system configured to identify, evaluate, and avoid or otherwise negotiate obstacles in the environment in which vehicle **200** is located. Control system **206** may additionally or alternatively include components other than those shown.

Peripherals **208** (e.g., input interface, output interface, etc.) may be configured to allow vehicle **200** to interact with external sensors, other vehicles, external computing devices, and/or a user. To this end, peripherals **208** may include, for example, a wireless communication system **252**, a touchscreen **254**, a microphone **256**, and/or a speaker **258**.

Wireless communication system **252** may be any system configured to wirelessly couple to one or more other vehicles, sensors, or other entities, either directly or via a communication network. To this end, wireless communication system **252** may include an antenna and a chipset for communicating with the other vehicles, sensors, servers, or other entities either directly or via a communication network. Chipset or wireless communication system **252** in general may be arranged to communicate according to one or more types of wireless communication (e.g., protocols) such as Bluetooth, communication protocols described in IEEE 802.11 (including any IEEE 802.11 revisions), cellular technology (such as GSM, CDMA, UMTS, EV-DO, WiMAX, or LTE), Zigbee, dedicated short range communications (DSRC), and radio frequency identification (RFID) communications, among other possibilities. Wireless communication system **252** may take other forms as well.

Touchscreen **254** may be used by a user as an input interface to input commands to vehicle **200**. To this end, touchscreen **254** may be configured to sense at least one of a position and a movement of a user's finger via capacitive sensing, resistance sensing, or a surface acoustic wave process, among other possibilities. Touchscreen **254** may be capable of sensing finger movement in a direction parallel or planar to the touchscreen surface, in a direction normal to the touchscreen surface, or both, and may also be capable of sensing a level of pressure applied to the touchscreen surface. Touchscreen **254** may be formed of one or more translucent or transparent insulating layers and one or more translucent or transparent conducting layers. Touchscreen **254** may take other forms as well.

Microphone **256** may be configured to receive audio (e.g., a voice command or other audio input) from a user of vehicle **200**. Similarly, speakers **258** may be configured to output audio to the user of vehicle **200**. Peripherals **208** may additionally or alternatively include components other than those shown.

Computer system **210** may be configured to transmit data to, receive data from, interact with, and/or control one or more of propulsion system **202**, sensor system **204**, control system **206**, and peripherals **208**. To this end, computer system **210** may be communicatively linked to one or more of propulsion system **202**, sensor system **204**, control system

**206**, and peripherals **208** by a system bus, network, and/or other connection mechanism (not shown).

In one example, computer system **210** may be configured to control operation of transmission **222** to improve fuel efficiency. As another example, computer system **210** may be configured to cause camera **234** to capture images of the environment. As yet another example, computer system **210** may be configured to store and execute instructions corresponding to sensor fusion algorithm **244**. Other examples are possible as well.

As shown, computer system **210** includes processor **212** and data storage **214**. Processor **212** may comprise one or more general-purpose processors and/or one or more special-purpose processors. To the extent processor **212** includes more than one processor, such processors could work separately or in combination. Data storage **214**, in turn, may comprise one or more volatile and/or one or more non-volatile storage components, such as optical, magnetic, and/or organic storage among other possibilities, and data storage **214** may be integrated in whole or in part with processor **212**.

In some embodiments, data storage **214** contains instructions **216** (e.g., program logic) executable by processor **212** to execute various vehicle functions. Data storage **214** may contain additional instructions as well, including instructions to transmit data to, receive data from, interact with, and/or control one or more of propulsion system **202**, sensor system **204**, control system **206**, and/or peripherals **208**. In some embodiments, data storage **214** also contains calibration data for one or more of the sensors in sensor system **204**. For example, the calibration data may include a mapping between previously obtained sensor measurements and one or more predetermined inputs to the sensors. Computer system **210** may additionally or alternatively include components other than those shown.

Power supply **260** may be configured to provide power to some or all of the components of vehicle **200**. To this end, power supply **260** may include, for example, a rechargeable lithium-ion or lead-acid battery. In some embodiments, one or more banks of batteries could be configured to provide electrical power. Other power supply materials and configurations are possible as well. In some embodiments, power supply **260** and energy source **220** may be implemented together as one component, as in some all-electric cars for instance.

In some embodiments, vehicle **200** may include one or more elements in addition to or instead of those shown. For example, vehicle **200** may include one or more additional interfaces and/or power supplies. Other additional components are possible as well. In such embodiments, data storage **214** may further include instructions executable by processor **212** to control and/or communicate with the additional components. Still further, while each of the components and systems are shown to be integrated in vehicle **200**, in some embodiments, one or more components or systems can be removably mounted on or otherwise connected (mechanically or electrically) to vehicle **200** using wired or wireless connections.

### III. Example Rotary Joint Configurations

Within examples, a rotary joint may be configured as an interface between two structures of an electromechanical system, in which one or both of the two structures is configured to rotate or otherwise move relative to the other structure. To that end, in some implementations, a portion of the rotary joint (e.g., rotor) may be coupled to one structure of the example system and another portion (e.g., stator) may be coupled to the other structure of the example system.

11

Additionally or alternatively, in some implementations, the rotary joint may be included within a structure arranged between two structures that rotate (or move) with respect to one another. For instance, an example rotary joint could be disposed in a robotic joint that couples two robotic links. Other implementations are possible as well.

FIG. 3 is a simplified block diagram of a device 300 that includes a rotary joint, according to an example embodiment. For example, device 300 can be used as an interface between moveable components of an electromechanical system, such as any of vehicles 100, 200, and/or any other electromechanical system. Thus, for instance, device 300 can be physically implemented as a rotary joint that facilitates power transmission between two moveable components of the system (or subsystem), such as a rotating platform that mounts sensors included in sensor units 102, 104, 106, 108, 110, sensor system 204, among other examples. As shown, device 300 includes a first platform 310 and a second platform 330.

First platform 310 may comprise or may be coupled to a rotor or other moveable component. For example, platform 310 can be configured to rotate relative to platform 330 and about an axis of rotation of platform 310 (e.g., rotor axis). Thus, within examples, platform 310 can be configured as a rotating platform in a rotary joint configuration. As shown, platform 310 includes a sensor 312, a controller 314, a communication interface 316, a power interface 318, and one or more magnets 320.

In some examples, platform 310 may comprise any solid material suitable for supporting and/or mounting various components of platform 310. For instance, platform 310 may include a printed circuit board (PCB) that mounts communication interface 316 and/or other components of platform 310. The PCB in this instance can also include circuitry (not shown) to electrically couple one or more of the components of platform 310 (e.g., sensor 312, controller 314, communication interface 316, power interface 318, etc.) to one another. The PCB in this instance can be positioned such that the mounted components are along a side of platform 310 facing or opposite to a corresponding side of platform 330. With this arrangement, for instance, platforms 310 and 330 may remain within a predetermined distance to one another in response to a rotation of platform 310 relative to platform 330.

Sensor 312 may include any combination of sensors mounted to platform 310, such as one or more sensors of sensor system 204, one or more of the sensors included in vehicle 100, and/or any other sensor that can be mounted on platform 310. A non-exhaustive list of example sensors may include direction sensors (e.g., gyroscopes), remote sensing devices (e.g., RADARs, LIDARs, etc.), sound sensors (e.g., microphones), among other examples.

Controller 314 may be configured to operate one or more of the components of first platform 310. To that end, controller 314 may include any combination of general-purpose processors, special-purpose-processors, data storage, logic circuitry, and/or any other circuitry configured to operate one or more components of device 300. In one implementation, similarly to computing system 210, controller 314 includes one or more processors (e.g., processor 212) that execute instructions (e.g., instructions 216) stored in data storage (e.g., data storage 214) to operate sensor 312, interface 316, etc. In another implementation, controller 314 alternatively or additionally includes circuitry wired to perform one or more of the functions and processes described herein for operating one or more components of device 300. In one example, controller 314 can be configured to receive

12

sensor data collected by sensor 312, and to provide a modulated electrical signal indicative of the sensor data to communication interface 316. For instance, the sensor data may indicate a measured orientation of sensor 312, a scan of a surrounding environment, detected sounds, and/or any other sensor output of sensor 312.

Communication interface 316 may include any combination of wireless or wired communication components (e.g., transmitters, receivers, antennas, light sources, light detectors, etc.) configured to transmit (e.g., signal 302) and/or receive (e.g., signal 304) data and/or instructions between platforms 310 and 330. In one example, where communication interface 316 is an optical communication interface, interface 316 may include one or more light sources arranged to emit modulated light signal 302 for receipt by a light detector included in platform 330. For instance, signal 302 may indicate sensor data collected by sensor 312. Further, in this example, interface 316 may include a light detector for receiving modulated light signal 304 emitted from platform 330. For instance, signal 304 may indicate instructions for operating sensor 312 and/or any other component coupled to platform 310. In this instance, controller 314 can operate sensor 312 based on the received instructions detected via interface 316.

Power interface 318 may include one or more components configured for wireless (or wired) transmission of power between platforms 310 and 330. By way of example, interface 318 may include transformer coil(s) (not shown) arranged to receive a magnetic flux extending through the transformer coils to induce an electrical current for powering one or more components (e.g., sensor 312, controller 314, communication interface 316, etc.) of platform 310. For instance, the transformer coils can be arranged around a center region of platform 310 opposite to corresponding transformer coils included in platform 330. Further, for instance, device 300 may also include a magnetic core (not shown) extending through the transformer coils in interface 318 (and/or transformer coils included in platform 330) to guide the magnetic flux through the respective transformer coils thereby improving efficiency of power transmission between the two platforms. Other configurations are possible as well.

Magnet(s) 320 may can be formed from a ferromagnetic material such as iron, ferromagnetic compounds, ferrites, etc., and/or any other material that is magnetized to generate a first-platform magnetic field of platform 310.

In one implementation, magnets 320 can be implemented as a plurality of magnets in a substantially circular arrangement around an axis of rotation of platform 310. For example, magnets 320 can be arranged along a circle that is concentric to the axis of rotation to generate a combined magnetic field extending toward and/or through platform 330. Further, for instance, adjacent magnets of magnets 320 can be magnetized in alternating directions such that a magnetic pole of a given magnet along a surface of the given magnet that is facing platform 330 is opposite to a magnetic pole of an adjacent magnet along a similar surface. With this arrangement for instance, a magnetic field may extend from the surface of the given magnet toward platform 330 and then toward the surface of the adjacent magnet. Further, another magnetic field may extend from a surface of the given magnet toward platform 330 and then toward another adjacent magnet.

In another implementation, magnet 320 can be implemented as a single ring magnet that is concentric to the axis of rotation of the first platform. In this implementation, the ring magnet can be magnetized to have a magnetization

pattern similar to that of the plurality of magnets described above. For example, the ring magnet can be implemented as a printed magnet having a plurality of ring sectors (e.g., regions of the ring magnet between respective radial axes thereof). In this example, adjacent ring sectors of the ring magnet can be magnetized in alternating directions to define a plurality of alternating magnetic poles facing platform 330.

As shown, magnet(s) 320 can optionally include an index magnet 322. Index magnet 322 may include a magnet (e.g., ferromagnetic material, etc.) that is configured to have a characteristic that differs from that of the other magnets in magnets 320.

In a first example, where magnets 320 include a plurality of magnets in a circular arrangement, index magnet 322 can be positioned at a first distance to the axis of rotation of platform 310, and the other magnets in magnets 320 can be positioned at a second distance to the axis of rotation that differs from the first distance. Additionally or alternatively, for instance, index magnet 322 can be positioned at an offset distance to the second platform relative to a substantially uniform distance between the other magnets and the second platform. Additionally or alternatively, for instance, index magnet 322 can be positioned at a particular separation distance to one or more adjacent magnets. In this instance, the other magnets can be spaced apart by a substantially uniform separation distance that differs from the particular separation distance.

In a second example, index magnet 322 can have a first size (e.g., width, length, depth, etc.) that differs from a second size of the other magnets in magnets 320.

In a third example, index magnet 322 can be magnetized to have a first magnetization strength (e.g., magnetic flux density, magnetic field strength, etc.) that differs from a second magnetization strength of the other magnets in magnets 320.

In a fourth example, index magnet 322 can be magnetized to have a different magnetization pattern compared to magnetization patterns of the other magnets in magnets 320. For instance, a first portion of index magnet 322 can be magnetized in a first direction (e.g., North Pole pointing toward platform 330) and a second portion of index magnet 322 can be magnetized in a second direction opposite to the first direction (e.g., South Pole pointing toward platform 330), whereas, the other magnets in magnets 320 can be magnetized in a single direction (e.g., only one of North Pole or South Pole pointing toward platform 330).

In a fifth example, where magnet(s) 320 comprise a single ring magnet, index magnet 322 can be implemented as an index ring sector of magnet 320 that includes a first portion magnetized in a first direction, and a second portion magnetized in an opposite direction. Alternatively or additionally, the second portion can be physically implemented as a magnetized region of magnet 320 that surrounds the first portion and connects with two ring sector that are adjacent to the index ring sector.

In a sixth example, where magnet(s) 320 comprise a single ring magnet, the various differentiating characteristics described above for an implementation that comprises a plurality of magnets can be similarly implemented by adjusting the magnetization properties of the ring magnet. In one instance, the index ring sector can have a different size (e.g., angular width, etc.) relative to substantially uniform sizes of other ring sectors. In another instance, the index ring sector can be separated from adjacent ring sectors by a different distance than a corresponding substantially uniform distance

between the other ring sectors (e.g., surrounding the index ring sector by demagnetized regions of the ring magnet, etc.).

Second platform 330 can be configured as a stator platform in a rotary joint configuration, in line with the discussion above. For instance, the axis of rotation of platform 310 can extend through platform 330 such that platform 310 rotates relative to platform 330 while remaining within a predetermined distance to platform 330. As shown, platform 330 includes a controller 334, a communication interface 336, a power interface 338, a plurality of conductive structures 340, circuitry 350, and a magnetic field sensor 390. Thus, for example, platform 330 can be formed from any combination of solid materials suitable for supporting the various components mounted or otherwise coupled to platform 330. For instance, platform 330 may comprise a circuit board that mounts one or more components (e.g., interfaces 336, 338, sensor 390, etc.).

Controller 390 can have various physical implementations (e.g., processors, logic circuitry, analog circuitry, data storage, etc.) similarly to controller 314, for example. Further, controller 390 can operate communication interface 336 to transmit signal 304 indicating a transmission of data or instructions similarly to, respectively, controller 314, communication interface 316, and signal 302. For instance, controller 390 can operate interface 336 (e.g., transceiver, antenna, light sources, etc.) to provide a modulated wireless signal indicating instructions for operating sensor 312 and/or any other component of platform 310. Further, for instance, controller 390 can receive a modulated electrical signal from interface 336 indicating modulated signal 302 transmitted from platform 310.

Accordingly, communication interface 336 can be implemented similarly to communication interface 316 to facilitate communication between platforms 310 and 330 via signals 302 and 304.

Power interface 338 can be configured similarly to power interface 318, and may thus be operated in conjunction with power interface 318 to facilitate transmission of power between platforms 310 and 330. By way of example, interface 338 may comprise a transformer coil (not shown), and controller 334 can be configured to cause an electrical current to flow through the transformer coil. The electrical current may then generate a magnetic flux that extends through a corresponding transformer coil (not shown) of power interface 318 to induce an electrical current through the corresponding transformer coil. The induced electrical current could thus provide power for one or more components of platform 310. Further, in some instances, device 300 may also include a magnetic core (not shown) extending along the axis of rotation of platform 310 and through the respective transformer coils (not shown) of power interfaces 318 and 338. The magnetic core, for instance, can guide the magnetic flux generated by a transformer coil of power interface 338 through a transformer coil of power interface 318 to improve efficiency of power transmission between platforms 310 and 330.

Conductive structures 340 may comprise portions of electrically conductive material (e.g., copper, other metal, etc.) that are electrically coupled together to define an electrically conductive path that extends around the axis of rotation of platform 310 to overlap the first-platform magnetic field generated by magnet(s) 320. By way of example, conductive structures 340 may include a first plurality of conductive structures in a first coplanar arrangement along a circle that is concentric to the axis of rotation of platform 310. Further, in this example, conductive structures 340 may

also include a second plurality of conductive structures in a second coplanar arrangement to overlap parallel to the first plurality of conductive structures. For instance, in a circuit board implementation, the first plurality of conductive structures can be disposed or patterned along a single layer of the circuit board, and the second plurality of conductive structures can be disposed or patterned along another layer of the circuit board.

Continuing with the example above, device **300** could also include a plurality of electrical contacts (not shown), such as conductive material that extends through a drilled hole between two layers of a circuit board (e.g., via) for instance. The electrical contacts may couple the first plurality of conductive structures to the second plurality of conductive structures to define one or more conductive coils extending around the axis of rotation to overlap the circular arrangement of magnet(s) **320** of the first platform. Circuitry **350** (and/or controller **334**) can then cause one or more electrical currents to flow through the one or more coils to generate a second-platform magnetic field extending within the one or more coils. The first-platform magnetic field could then interact with the second-platform magnetic field to provide a force or torque acting on platform **310**. The induced force may then cause platform **310** to rotate about the axis of rotation thereof. Further, in some instances, circuitry **350** (and/or controller **334**) can modulate the second-platform magnetic field by adjusting the electrical current(s) flowing through the coil(s). By doing so, for instance, device **300** can control a direction or rate of rotation of platform **310** about the axis of rotation.

Accordingly, circuitry **350** may include any combination of wiring, conductive material, capacitors, resistors, amplifiers, filters, comparators, voltage regulators, controllers, and/or any other circuitry arranged to provide and modulate electrical current(s) flowing through conductive structures **340**. For instance, circuitry **350** may be configured to condition the electrical current(s) to modify the second-platform magnetic field and thereby achieve certain rotation characteristics (e.g., direction, speed, etc.) for rotating platform **310**.

Magnetic field sensor **390** may be configured to measure one or more characteristics (e.g., direction, angle, magnitude, flux density, etc.) of the first-platform magnetic field associated with magnet(s) **320**. For example, sensor **390** may include one or more magnetometers arranged to overlap magnet(s) **320** and/or the first-platform magnetic field. A non-exhaustive list of example sensors includes proton magnetometers, Overhauser effect sensors, cesium vapor sensors, potassium vapor sensors, rotating coil sensors, Hall effect sensors, magneto-resistive device sensors, fluxgate magnetometers, superconducting quantum interference device (SQUID) sensors, micro-electro-mechanical-system (MEMS) sensors, and spin-exchange relaxation-free (SERF) atomic sensors, among other examples. In one implementation, sensor **390** may comprise a three-dimensional (3D) Hall effect sensor that outputs an indication of an angle (and/or magnitude) of the first-platform magnetic field at a position of sensor **390** according to an orthogonal coordinate system representation (e.g., x-y-z axis components) or other vector field representation.

Thus, device **300** could use output(s) from sensor **390** as a basis for determining an orientation or position of platform **310** about the axis of rotation. By way of example, sensor **390** can be positioned to overlap a portion of the first-platform magnetic field extending between two adjacent magnets of magnet(s) **320**. As first platform **310** rotates, for instance, the angle of the portion may change at the position

of sensor **390** and thus circuitry **350** (and/or controller **334**) can sample the outputs from sensor **390** to deduce the position of sensor **390** relative to the two adjacent magnets.

Thus, with this arrangement, device **300** could use magnet(s) **320** as component(s) for both actuating platform **310** and measuring the orientation of platform **310** (e.g., magnetic encoder). This arrangement can provide an actuator and a magnetic encoder with reduced costs and with a more compact design.

Additionally, in some implementations, sensor **390** can be positioned along a circular path that intersects with the coil(s) defined by structures **340**. For example, two particular structures in structures **340** can be spaced apart by a given distance greater than a uniform distance between other adjacent structures in structures **340**. Further, sensor **390** can be positioned between these two particular structures. With this arrangement, for instance, interference due to the second-platform magnetic field with measurements of the first-platform magnetic field by sensor **390** can be mitigated, while also placing sensor **390** at a close distance to magnet(s) **320**.

In implementations where magnet(s) **320** include index magnet **322**, a particular portion of the first-platform magnetic field extending between index magnet **322** and one or more magnets adjacent to index magnet **322** may have one or more differentiating characteristics relative to other portions of the first-platform magnetic field. By of example, if index magnet **322** is positioned at a different distance to the axis of rotation of platform **310** than a substantially uniform distance between the axis of rotation and other magnets of magnet(s) **320**, then a direction of the particular portion of the first-platform magnetic field may differ from respective directions of the other portions. Accordingly, in some examples, circuitry **350** (and/or controller **334**) can associate detection of this difference with an orientation of platform **310** where sensor **390** overlaps index magnet **322** or a region between index magnet **322** and an adjacent magnet. Through this process, for instance, device **300** can map outputs of sensor **390** to a range of orientations of platform **310** relative to a position of index magnet **322**.

In some implementations, device **300** may include fewer components than those shown. For example, device **300** can be implemented without index magnet **322**, sensor **390**, and/or any other component shown. Further, in some implementations, device **300** may include one or more components in addition to or instead of those shown. For example, platforms **310** and/or **340** may include additional or alternative sensors (e.g., microphone **256**, etc.), computing subsystems (e.g., navigation system **248**, etc.), and/or any other component such as any of the components of vehicles **100** and **200**. Additionally, it is noted that the various functional blocks shown can be arranged or combined in different arrangements than those shown. For example, some of the components included in platform **310** can be alternatively included in platform **330** or implemented as separate components of device **300**.

FIG. 4A illustrates a side view of a device **400** that includes a rotary joint, according to an example embodiment. For example, device **400** may be similar to device **300**, and can be used with an electromechanical system such as vehicles **100** and **200**. As shown, device **400** includes a rotor platform **410** and a stator platform **430** that may be similar, respectively, to platforms **310** and **330**. In the example shown, a side **410a** of platform **410** is positioned at a predetermined distance **408** to a side **430a** of platform **430**. Platform **410** can be configured as a rotor platform that rotates about axis of rotation **406**. Further, platform **430** can

be configured as a stator platform that remains within distance **408** to platform **410** in response to rotation of platform **410** about axis **406**. In some examples, side **410a** may correspond to a planar mounting surface of platform **410** (e.g., an outer layer of a circuit board). Similarly, for example, side **430a** may correspond to a planar mounting surface of platform **430**. It is noted that some components of device **400** are omitted from FIG. 4A for convenience in description.

In the cross section view shown in FIG. 4B for instance, side **410a** of platform **410** is pointing out of the page. As shown in FIG. 4B, device **400** also includes a plurality of magnets, exemplified by magnets **420**, **422**, **424**, **426**, and a mount **428**.

Magnets **420**, **422**, **424**, **426**, can be similar to magnet(s) **320**. For example, as shown, magnets **420**, **422**, **424**, **426**, are mounted in a substantially circular arrangement around axis of rotation **406**. In some examples, like magnet(s) **320**, adjacent magnets of the plurality of magnets (e.g., **420**, **422**, **424**, **426**, etc.) can be respectively magnetized in alternating directions. For example, as shown, magnet **420** is magnetized in a direction pointing into the page (e.g., South Pole indicated by letter "S" pointing out of the page), magnet **422** is magnetized in a direction pointing out of the page (e.g., North Pole indicated by letter "N" pointing out of the page), magnet **424** is magnetized in the same direction as magnet **420**, and so on. Thus, in some examples, the respective magnetization directions of the plurality of magnets (e.g., **420**, **422**, **424**, **426**, etc.) could be substantially parallel to axis **406**, as shown.

Mount **428** may include any structure configured to support the plurality of magnets (e.g., **420**, **422**, **424**, **426**, etc.) in a circular arrangement around axis of rotation **406**. To that end, mount **428** may include any solid structure (e.g., plastic, aluminum, other metal, etc.) suitable for supporting the plurality of magnets in the circular arrangement. For example, as shown, mount **428** can have a ring shape extending between (circular) edges **428a** and **428b**. Further, as shown, mount **428** may include indentations that accommodate the plurality of magnets in the circular arrangement. For instance, as shown, mount **428** includes an indentation (between walls **428c** and **428d**) shaped to accommodate magnet **426**. Thus, during assembly for instance, the plurality of magnets could be fitted into respective indentations of mount **328** to facilitate placing the plurality of magnets in the circular arrangement. Further, as shown, ring-shaped mount **428** could be concentrically arranged relative to axis **406** (e.g., axis **406** aligned with a center axis of ring-shaped mount **428**). Thus, for instance, circular edges **428a**, **428b**, and magnets **420**, **422**, **424**, **426**, etc., could remain within respective given distances to axis **406** in response to rotation of platform **410** about axis **406**.

In some examples, similarly to index magnet **322**, at least one magnet in device **400** can be configured as an index magnet having one or more characteristics that differ from a common characteristic of other magnets. As shown, for example, magnet **422** is mounted at a different distance to axis **406** than a distance between other magnets (e.g., **420**, **424**, **426**, etc.) and axis **406**. To facilitate this, as shown, an indentation (e.g., defined by wall **428e** extending around the indentation) that accommodates index magnet **422** could have a smaller length than respective indentations accommodating magnets **420**, **424**, **426**, etc. As a result, index magnet **422**, when mounted, may be closer to edge **428a** (and axis **406**) than magnets **420**, **424**, **426**, etc.

It is noted that platform **410** may include additional components to those shown in FIG. 4B. In one implemen-

tation, mount **428** can be arranged along a periphery of a printed circuit board (PCB) or other circuit board. In another implementation, mount **428** can be disposed along a surface or layer of the circuit board. Regardless of the implementation, for example, the region of side **410a** between axis **406** and edge **428a** can be used to mount one or more components such as any of the components of platform **310**.

In one example, as shown, platform **410** may include a center gap defined by edge **410b**. In this example, platform **410** may include a transformer coil (not shown) arranged around edge **410b**. Further, in this example, device **400** may include a magnetic core (not shown) extending through the center gap to guide a magnetic flux generated by a similar transformer coil (not shown) of platform **430**. Thus, for instance, power can be transmitted between the two platforms **410** and **430**, in line with the discussion above for power interfaces **318** and **338**. In another example, platform **410** may include one or more wireless transmitters or receivers (e.g., light sources, light detectors, antenna, etc.) in the region of platform **410** between edges **428a** and **410b**. Thus, similarly to device **300** for example, device **400** can be configured to transmit power and/or communication signals between platforms **410** and **430**.

In the cross section view shown in FIG. 4C, side **430a** of platform **430** is pointing out of the page. The cross section view of platform **430** shown in FIG. 4D may correspond to a view of a layer of platform **430** that is substantially parallel to side **430a**. Referring back to FIG. 4A by way of example, the layer shown in FIG. 4D may correspond to a layer between sides **430a** and **430b**. In another example, the layer shown in FIG. 4D may correspond to conductive materials patterned on side **430b** of platform **430**. In one implementation, platform **430** can be physically implemented as a multi-layer circuit board (e.g., PCB) or may comprise a multi-layer PCB embedded therein. To that end, one or more components shown in FIG. 4C may correspond to electrically conductive material(s) (e.g., tracks, traces, copper, etc.) patterned along an outer layer of the PCB, and one or more components shown in FIG. 4D may correspond to electrically conductive material(s) patterned along another layer of the PCB. Other implementations are possible as well.

As shown in FIGS. 4C and 4D, device **400** also includes a plurality of power leads, exemplified by leads **432**, **434**, **436**, **438**, a first plurality of adjacent conductive structures, exemplified by structures **442**, **444**, **446**, **448**, **450**, **452**, **454**, **456**, **458**, **459**, a second plurality of adjacent conductive structures, exemplified by structures **472**, **474**, **476**, **478**, **480**, **482**, **484**, **486**, **489**, a plurality of electrical contacts, exemplified by contacts **462**, **464**, **466**, **468**, a magnetic field sensor **490**, and connectors **492**, **494**.

Power leads **432**, **434**, **436**, **438**, etc., may be configured to electrically couple, respectively, one or more of the first and second pluralities of conductive structures to a power source, voltage regulator, current amplifier, or other circuitry (e.g., circuitry **350**) that provides or conditions one or more electrical currents flowing through the respective conductive tracks coupled to the respective leads.

The first plurality of conductive structures (**442**, **444**, **446**, **448**, **450**, **452**, **454**, **456**, **458**, **459**, etc.) may comprise electrically conductive material (e.g., copper, etc.) in a circular arrangement around axis **406**, similarly to conductive structures **340**. For instance, as shown in FIG. 4C, the first plurality of conductive structures extends between circles **440** and **441**, which are concentric to axis **406**. A region of side **430a** between circles **440** and **441**, for instance, may at least partially overlap the plurality of magnets **420**, **422**, **424**, **426**, etc., of rotor platform **410**.

Further, as shown in FIG. 4C, each conductive structure (e.g., structure 442, etc.) is tilted relative to a radius of circle 440 (and 441) where the respective structure intersects with circle 440. In addition, the first plurality of conductive structures is in a substantially coplanar arrangement. Thus, for instance, structures 442, 444, 446 448, 450, 452, 454, 456, 458, 459, etc. can be formed as patterned conductive tracks along a single layer of a circuit board (e.g., PCB).

Similarly, in FIG. 4D, the second plurality of conductive structures (472, 474, 476, 478, 480, 482, 484, 486, 488, 489, etc.) are in a circular arrangement that is substantially coplanar (e.g., along a second layer of the PCB). Thus, for example, the first plurality of conductive structures may be at a first distance to the plurality of magnets (420, 422, 424, 426, etc.) that is less than a second distance between the second plurality of structures and the plurality of magnets.

Additionally, structures 472, 474, 476, 478, 480, 482, 484, 486, 488, 489, etc. extend, respectively, between circles 470 and 471. Circles 470 and 471 may be similar to circles 440 and 441, for example, and may thus be concentric to axis 406 with similar radii, respectively, as the radii of circles 440 and 441. Further, each conductive structure (e.g., structure 472, etc.) in FIG. 4D is positioned at a tilting angle relative to a radius of circle 470 (and 471) where the respective structure intersects with circle 470. However, the second plurality of structures in FIG. 4D are at an opposite tilting angle to the tilting angle of the first plurality of structures of FIG. 4C. For example, structure 442 (FIG. 4C) is shown to tilt away from circle 440 in a clockwise direction. Whereas, structure 472 (FIG. 4D) is shown to tilt away from circle 470 in a counterclockwise direction.

To facilitate electrically coupling between the first plurality of structures (442, 444, 446, 448, 450, 452, 454, 456, 458, 459, etc.) and the second plurality of structures (472, 474, 476, 478, 480, 482, 484, 486, 488, 489, etc.), electrical contacts 462, 464, 466, 468, etc., may comprise conductive material that extends through the PCB in a direction perpendicular to the page (e.g., vias) to connect respective conductive structures that overlap at the respective positions of the respective contacts. For example, contact 462 electrically couples conductive structure 442 (FIG. 4C) to conductive structure 472 (FIG. 4D), contact 464 electrically couples conductive structure 444 (FIG. 4C) to conductive structure 474 (FIG. 4D), etc.

With this arrangement, the conductive structures in both layers of platform 430 may form one or more conductive paths that extend around axis 406. For example, a first current can flow through a first conductive path that comprises, in this order: lead 432, structure 442, contact 462, structure 472, contact 466, structure 446, etc., until the first current arrives at lead 436. Thus, for example, the first current can flow from structure 442 to structure 472 without flowing through adjacent structure 444. Similarly, for example, a second current can flow through a second conductive path that comprises, in this order: lead 434, structure 444, contact 464, structure 474, contact 468, structure 448, etc., until the second current arrives at lead 438. Thus, the first conductive path may form a first coil that extends around axis 406, and the second conductive path may form a second coil that extends around axis 406.

In some implementations, leads 432, 434, etc., of the first layer shown in FIG. 4C can be connected (directly or indirectly) to a first terminal of a power source (not shown), and leads 436, 438, etc., of the second layer shown in FIG. 4D can be connected to a second terminal of the power source. As a result, in these implementations, each coil or conductive path of platform 430 may carry a portion of a

same electrical current. For instance, each coil in these implementations may be connected to other coils in a parallel circuit configuration.

Regardless of the implementation, when electrical current(s) are flowing through the first and second pluralities of coplanar conductive structures, a stator-platform magnetic field is generated through the coil(s) formed by the electrically coupled conductive structures. The stator-platform magnetic field could then interact with the rotor-platform magnetic field associated with the magnets in rotor platform 410 to cause a torque or force that rotates platform 410 about axis 406. The stator-platform magnetic field, for example, may extend within the coil(s) defined by the first and second conductive paths described above in a clockwise or counterclockwise direction depending on a direction of the respective electrical currents flowing through the respective conductive paths (or coils).

Thus, in some examples, the conductive structures shown in FIGS. 4C and 4D can be electrically coupled to form a coreless PCB motor coil. For instance, the first plurality of conductive structures shown in FIG. 4C can be separated from the second plurality of conductive structures shown in FIG. 4D by an insulating material, such as an electrically insulating layer (e.g., plastic, etc.) between the two layers shown in FIGS. 4C and 4D. In this instance, the stator-platform magnetic field could extend through the insulating material. However, in other examples, a magnetically permeable core (not shown) can be inserted between the two layers of FIGS. 4C and 4D to direct the generated stator-platform magnetic field. For instance, a middle layer (not shown) of platform 430 may include conductive material disposed between the two layers of FIGS. 4C and 4D. In this instance, the conductive material in the middle layer could also overlap the first plurality of conductive structures and the second plurality of conductive structures. As a result, the conductive material in the middle layer may thus be configured as a magnetic core that enhances the stator-platform magnetic field by directing the stator-platform magnetic field inside coil(s) defined by the respective conductive path(s) extending around axis 406 and along the two layers shown in FIGS. 4C and 4D.

Magnetic field sensor 490 may be similar to sensor 390. To that end, sensor 490 may include any magnetometer, such as a Hall effect sensor, etc., that is configured to measure the rotor-platform magnetic field generated by the magnets (e.g., 420, 422, 424, 426, etc.) of platform 410. Thus, for instance, a computing system (e.g., controller 334, circuitry 350, etc.) can determine an orientation of platform 410 about axis 406 based on outputs from sensor 490.

To facilitate this, in some examples, sensor 490 can be positioned at a location in platform 430 that substantially overlaps the rotor-platform magnetic field of platform 410. For example, as shown in FIG. 4C, sensor 490 is positioned in the region between circles 440 and 441 (the region that at least partially overlaps the magnets of platform 410). Additionally, to mitigate interference due to the stator-platform magnetic field extending between the coils or conductive paths defined by the first and second pluralities of conductive structures, a portion of the coil-shaped conductive path extending around axis 406 in platform 430 could be interrupted or modified in the region of platform 430 where sensor 490 is located.

As shown in FIG. 4C, for example, the first plurality of conductive structures comprise a plurality of spaced-apart conductive structures that are spaced apart by a substantially uniform distance. For instance, as shown, structures 442, 444 are separated by the substantially uniform distance, and

structures 446, 448 are also separated by the substantially uniform distance. Further, the first plurality of conductive structures shown in FIG. 4C may include two adjacent structures that are separated by a greater distance than the substantially uniform distance. For instance, as shown, adjacent structures 454 and 456 are separated by the greater distance. Similarly, for example, the second plurality of conductive structures (shown in FIG. 4D) also includes two adjacent structures (e.g., 484, 486) that are separated by a greater distance than the substantially uniform distance between other structures of the second plurality of structures. Thus, as shown in FIG. 4C, sensor 490 can be located between structures 454 and 456 (i.e., within the “gap” in the coil-shaped conductive path(s) extending around axis 406).

To facilitate this arrangement, connectors 492 and 494, which extend away from the region where sensor 490 is located (e.g., outside the region between circles 440 and 441, etc.), can be employed to electrically couple a portion of the coil-shaped conductive path(s) and a remaining portion of the coil-shaped conductive path(s). To that end, connectors 492 and 494 may comprise conductive material (e.g., copper, metal, metal compound, etc.) that is shaped and/or disposed at an appropriate distance from sensor 490 to reduce the effect of the stator-platform magnetic field at a location of sensor 490.

As shown, for instance, connector 492 electrically couples, via an electrical contact, conductive structure 454 (FIG. 4C) to conductive structure 489 (FIG. 4D). Similarly, connector 494 electrically couples conductive structure 484 (FIG. 4D) to conductive structure 459 (FIG. 4C). Although not shown, platform 430 may also include additional connectors (e.g., similar to connectors 492 or 494) that are configured to electrically connect additional conductive paths around axis 406 while reducing the stator-platform magnetic field at the location of sensor 490. In a first example, a connector (not shown) could electrically couple structure 452 (FIG. 4C) to structure 488 (FIG. 4D). In a second example, a connector (not shown) could electrically couple structure 450 (FIG. 4C) to structure 486 (FIG. 4D). In a third example, a connector (not shown) could electrically couple structure 480 (FIG. 4D) to structure 456 (FIG. 4C). In a fourth example, a connector (not shown) could electrically couple structure 482 (FIG. 4D) to structure 458 (FIG. 4C).

Further, although connectors 492 and 494 are shown to be disposed along a same PCB layer (e.g., side 430a), in some examples, one or more connectors can be alternatively disposed along the layer shown in FIG. 4D or another layer (not shown) of platform 430. Further, although magnetic sensor 490 is shown to be mounted to side 430a of platform 430, in some examples, sensor 490 can be alternatively positioned along a different side (e.g., side 430b) of platform 430 or any other position within a portion of the rotor-platform magnetic field between conductive structures 454, 456, 484, 486. For instance, in an implementation where the second plurality of conductive structures 472, 474, 476, 478, 480, 482, 484, 486, 488, 489, etc. are disposed along side 430b of platform 430, sensor 490 can be alternatively mounted between structures 484 and 486. Other positions for sensor 490 are possible as well (e.g., between sides 430a and 430b, etc.).

Further, in some examples, platform 430 may include more components than those shown, such as any of the components (e.g., communication interface 335, power interface 338, etc.) included in platform 330 for instance. Referring back to FIG. 4C by way of example, platform 430 can be implemented as a circuit board (e.g., PCB), and the

region between axis 406 and circle 440 can include power interface components (e.g., transformer coils), and/or communication interface components (e.g., wireless transmitters, light sources, detectors, etc.), among other possibilities.

It is noted that the shapes, dimensions, and relative positions shown in FIGS. 4A-4D for device 400 and/or components thereof are not necessarily to scale and are only illustrated as shown for convenience in description. To that end, for example, device 400 and/or one or more components thereof can have other forms, shapes, arrangements, and/or dimensions as well. It is also noted that device 400 may include fewer or more components than those shown, such as any of the components of device 300 (e.g., interfaces, sensors, controllers, etc.), among others. In one example, although six leads are shown for each layer of FIGS. 4C and 4D, device 400 could alternatively include more or fewer leads for a different number of conductive paths extending around axis 406. In another example, although device 400 is shown to include a particular number of magnets in platform 410, device 400 can alternatively include more or fewer magnets.

FIG. 5 is a conceptual illustration 500 of the relationship between orientations of a rotor platform and outputs from a magnetic field sensor, according to an example embodiment. FIG. 5 illustrates a scenario where rotor platform 410 is rotated for a complete rotation at a constant rate and in a clockwise direction about axis 406. To that end, the horizontal axis of the plot in illustration 500 may indicate time (e.g., in seconds) from an initial orientation of platform 410 until platform 410 rotates for a complete (e.g., 360 degree) rotation about axis 406. In the scenario, sensor 490 may be configured to provide a 3D representation of the rotor-platform magnetic field at a location of sensor 490 (e.g., vector field). Thus, the X-curve, Y-curve, and Z-curve indicated in legend 502 may correspond, respectively, to an x-component, y-component, and z-component of the measured magnetic field by sensor 490. To that end, for plots X, Y, Z, the vertical axis of the plot in illustration 500 may indicate measured magnetic fields (e.g., in Teslas). Further, the curve “a tan 2(Z, X)” indicated in legend 502 may correspond to a computed magnetic field angle based on an application of the “a tan 2” function to the z-component and x-component of the output. The a tan 2 computation may be similar to computing an arc tangent of: the z-component output divided by the x-component output. However, unlike the arc tangent computation, the a tan 2 function provides an output angle in radians between the positive x-axis of a plane and the point given by the co-ordinates (X, Z) on the plane. For example, an a tan 2 computed angle may comprise a positive value for counter-clockwise angles (e.g., Z>0), and a negative value for clock-wise angles (e.g., Z<0). By doing so, unlike a simple arc tangent computation, a tan 2 can provide an output in the range of  $-\pi$  Radians to  $\pi$  Radians, while also avoiding the issue of division by zero (e.g., where the value of the x-component is zero). To that end, as shown for the curve of “a tan 2(Z, X),” the vertical axis may indicate an angular computation (e.g., in Radians).

Referring back to FIG. 4C, the y-component indicated by the Y-curve may correspond to a component of the rotor-platform magnetic field that is along a y-axis extending through sensor 490 toward axis 406. The z-component indicated by the Z-curve may correspond to a component of the rotor-platform magnetic field that is along a z-axis extending through sensor 490 and out of the page. The x-component indicated by the X-curve may correspond to a

component of the rotor-platform magnetic field along an x-axis of sensor 490 that is perpendicular (e.g., orthogonal) to the y-axis and the z-axis.

With this configuration, for instance, the maxima of the Z-curve shown in illustration 500 may correspond to orientations of platform 410 where sensor 490 is aligned with a magnet that is magnetized in a positive direction of the z-axis (e.g., South Pole pointing out of the page). For example, the z-maximum at arrow 504 indicates an orientation of platform 410 where magnet 420 is aligned with sensor 490. Further, the minima of the Z-curve may correspond to orientations of platform 410 where sensor 490 is aligned with a magnet that is magnetized in a negative direction of the z-axis (e.g., North Pole pointing out of the page). For example, the z-minimum at arrow 506 indicates an orientation of platform 410 where magnet 426 is aligned with sensor 490.

Thus, with this arrangement, an indication of the orientation of platform 410 between two adjacent magnets can be computed (e.g., the “a tan 2(Z, X)” curve) as the a tan 2 computation for: the z-component and the x-component. This computation, for example, can be performed by controller 334 and/or circuitry 350. The a tan 2(Z, X) curve represents a normalized orientation of platform 410 between any two magnets. For example, each orientation of platform 410 where sensor 490 is aligned with a magnet may correspond to a value of zero radians or a value of pi radians (depending on the direction of the z-axis). Thus the various devices and systems herein (e.g., vehicles 100, 200, devices 300, 400) can use the a tan 2(Z, X) computation as a mapping for orientations of platform 410 relative to any two magnets.

Further, as noted above, an index magnet can be used to facilitate computing an absolute orientation of platform 410 about axis 406. Referring back to FIG. 4B by way of example, index magnet 422 is positioned at an offset distance to axis 406 (i.e., an offset along the y-axis of sensor 490) compared to other magnets (e.g., 420, 424, 426, etc.) of platform 410. As a result, for example, the y-component of the rotor-platform magnetic field measured by sensor 490 may experience an anomaly for orientations of platform 410 where sensor 490 overlaps a region between magnets 420 and 424. Arrow 508 points to a y-maximum that is associated with the sensor 490 being in such region (e.g., between magnets 420 and 424). As shown, the y-maximum 508 is significantly lower than other y-maxima of the Y-curve in illustration 500. Thus, the y-component anomaly can be used by device 400 to detect an index position of platform 410, and then map other positions between different pairs of magnets as absolute orientations of platform 410 relative to the index position or orientation.

Further, as shown, the y-component anomaly is substantially independent from the x-component and z-component measurements. Thus, the y-axis displacement of index magnet 422 can allow device 400 to measure the orientation of platform 410 (e.g., using the x-component and z-component), while also detecting the index orientation using the y-component.

FIG. 6 is a cross-section view of another device 600 that includes a rotary joint, according to an example embodiment. For example, device 600 may be similar to devices 300 and 400. To that end, device 600 includes a rotor platform 610 having a side 610a, that are similar, respectively to rotor platform 410 and side 410a. Further, as shown, device 600 includes an axis of rotation 606, magnets 620, 624, 626, and mount 628, that are similar, respectively, to axis 406, magnets, 420, 424, 426, and mount 428.

As noted above, in some examples, index magnet 422 may have alternative or additional differentiating characteristics other than a displacement along the y-axis of sensor 490 (i.e., distance to axis 406). For example, unlike index magnet 422, index magnet 622 is at a same distance to axis 606 as other magnets (e.g., 620, 624, 626, etc.) of platform 610. However, as shown, index magnet 622 has a smaller size (e.g., length) compared to the other magnets. As a result, index magnet 622 may also exhibit an anomaly (e.g., similar to y-maximum 508) that allows device 600 to identify an index orientation of platform 610 about axis 606.

FIG. 7 is a cross-section view of another device 700 that includes a rotary joint, according to an example embodiment. For example, device 700 may be similar to devices 300, 400, 600. To that end, device 700 includes a rotor platform 710 and a side 710a that are similar, respectively, to rotor platform 410 and side 410a. Further, as shown, device 700 includes an axis of rotation 706, magnets 720, 724, 726, and mount 728 that are similar, respectively, to axis 406, magnets, 420, 424, 426, and mount 428.

However, unlike index magnet 422, index magnet 722 is at a same distance to axis 706 as other magnets (e.g., 720, 724, 726, etc.) of platform 710. Instead, as shown, index magnet 722 is arranged adjacent to another magnet 723 (e.g., within the indentation that accommodates magnet 722 in the circular arrangement of magnets around axis 706). Further, magnet 723 could be magnetized in a direction opposite to a magnetization direction of magnet 722 (e.g., indicated by South Pole “S” pointing out of the page). Thus, magnet 723 may distort the magnetic field provided by index magnet 722 such that index magnet 722 exhibits an anomaly (e.g., similar to y-maximum 508) that allows device 700 to identify an index position or orientation of platform 710 about axis 706.

Alternatively, although not shown, magnets 722 and 723 can be implemented as a single magnet (e.g., printed magnet, etc.) that includes a portion that is magnetized along one direction (e.g., South Pole pointing out of page) and another portion that is magnetized along an opposite direction (e.g., North Pole pointing out of page).

FIG. 8 is a cross-section view of another device 800 that includes a rotary joint, according to an example embodiment. For example, device 800 may be similar to devices 300, 400, 600, 700. To that end, device 800 includes a rotor platform 810 and a side 810a that are similar, respectively, to rotor platform 410 and side 410a. Further, as shown, device 800 includes an axis of rotation 806 that is similar to axis 406. As shown, device 800 also includes a ring magnet 820 that is similar to magnet 320.

As noted above, in some examples, magnet 320 can be implemented as a single ring magnet. Thus, as shown, ring magnet 820 is an example single magnet implementation that can be used instead of the plurality of magnets 420, 422, 424, 426, etc., of device 400. For example, ring magnet 820 can be physically implemented as a printed magnet that has a magnetization pattern similar to the arrangement of magnets in device 400 (e.g., adjacent regions of magnet 820 magnetized in alternating directions, etc.).

For example, a first ring sector (e.g., annulus sector, etc.) of ring magnet 820 may correspond to a region of magnet 820 having an angular width between radii 822 and 824. As shown, the first ring sector could be a magnetized region of ring magnet 820 that is magnetized in a first direction (parallel to axis 806) that is pointing into the page. This is illustrated by the white background of the first ring sector and the letter “S” (i.e., South Pole pointing out of the page). Similarly, for example, a second ring sector of ring magnet

**820** (adjacent to the first ring sector) may correspond to a region of magnet **820** having an angular width between radii **824** and **826**. Further, as shown, at least a portion of the second ring sector is magnetized in an opposite direction to that of the first ring sector. This is illustrated by the different background pattern of the second ring sector and the letter “N” (i.e., North Pole pointing out of the page).

Additionally, the second ring sector (between radii **824** and **826**) shows an alternative implementation for index magnet **422**. As shown, the region between radii **824** and **826** is configured as an index ring sector by magnetizing a portion of the index ring sector along a first direction (e.g., “N” North Pole pointing out of the page) and another portion of the index ring sector along an opposite direction (e.g., portion with a white background that has a same magnetization direction “S” South pole as adjacent ring sectors between radii **822**, **824** and radii **826**, **828**). Thus, the index ring sector of ring magnet **820** illustrates an alternative “index magnet” implementation that can also provide an anomaly (e.g., similar to y-maximum **508**) in an output of a magnetic field sensor (e.g., sensor **390**, **490**, etc.) to facilitate determining an absolute position or orientation of rotor platform **810** about axis **806**.

Additionally, in an example scenario where magnet **820** replaces magnets **420**, **422**, **424**, **426**, etc. of device **400**, conductive structures **442**, **444**, **446**, **448**, **450**, **452**, **454**, **456**, **458**, **459**, etc., may remain within predetermined distance **408** to magnet **820** in response to rotation of platform **410** about axis **406**. Further, in the scenario, an electrically conductive path defined by one or more of the conductive structures could remain at least partially overlapping ring magnet **820** as platform **410** rotates about axis **406**.

#### IV. Example Methods and Computer-Readable Media

FIG. **9** is a flowchart of a method **900**, according to an example embodiment. Method **900** shown in FIG. **9** presents an embodiment of a method that could be used with any of vehicles **100**, **200**, and/or devices **300**, **400**, **600**, **700**, **800**, for example. Method **900** may include one or more operations, functions, or actions as illustrated by one or more of blocks **902-904**. Although the blocks are illustrated in a sequential order, these blocks may in some instances be performed in parallel, and/or in a different order than those described herein. Also, the various blocks may be combined into fewer blocks, divided into additional blocks, and/or removed based upon the desired implementation.

In addition, for method **900** and other processes and methods disclosed herein, the flowchart shows functionality and operation of one possible implementation of present embodiments. In this regard, each block may represent a module, a segment, a portion of a manufacturing or operation process, or a portion of program code, which includes one or more instructions executable by a processor for implementing specific logical functions or steps in the process. The program code may be stored on any type of computer readable medium, for example, such as a storage device including a disk or hard drive. The computer readable medium may include a non-transitory computer readable medium, for example, such as computer-readable media that stores data for short periods of time like register memory, processor cache and Random Access Memory (RAM). The computer readable medium may also include non-transitory media, such as secondary or persistent long term storage, like read only memory (ROM), optical or magnetic disks, compact-disc read only memory (CD-ROM), for example. The computer readable media may also be any other volatile or non-volatile storage systems. The computer readable

medium may be considered a computer readable storage medium, for example, or a tangible storage device.

In addition, for method **900** and other processes and methods disclosed herein, each block in FIG. **9** may represent circuitry that is wired to perform the specific logical functions in the process.

Method **900** is an example method for rotating a rotor platform (e.g., first platform **310**, etc.) of a device (e.g., device **300**, etc.) relative a stator platform (e.g., second platform **330**, etc.) of the device and about an axis of rotation of the rotor platform (e.g., axis **406**, etc.). Thus, in some examples, the rotor platform may remain within a predetermined distance (e.g., distance **408**, etc.) to the stator platform in response to rotation of the rotor platform about the axis of rotation, in line with the discussion above.

At block **902**, method **900** involves causing an electrical current to flow through an electrically conductive path included in the stator platform and extending around the axis of rotation of the rotor platform. By way of example, device **300** may include circuitry **350** (e.g., power source(s), voltage regulator(s), current amplifier(s), wiring, etc.) that provides the electrical current to the electrically conductive path. To that end, for instance, the electrically conductive path may be defined by a first plurality of coplanar conductive structures (e.g., one or more of structures **442**, **444**, **446**, **448**, **450**, **452**, **454**, **456**, **458**, **459**, etc.) that are electrically coupled to one another. Further, for example, the electrically conductive path may also include a second plurality of coplanar conductive structures (e.g., one or more of structures **472**, **474**, **476**, **478**, **480**, **482**, **484**, **486**, **488**, **489**, etc.) that are parallel and electrically coupled to the first plurality of coplanar structures to form a coil extending around the axis of rotation.

Thus, as noted above, the electrical current flowing through the coil (i.e., arrangement of planar conductive structures) may generate a stator-platform magnetic field that interacts with a rotor-platform magnetic field of the rotor platform such that the rotor-platform rotates about the axis of rotation. For example, the interaction of the magnetic fields may induce a torque or force that causes the rotor platform to rotate about the axis of rotation in a clockwise or counterclockwise direction (depending on direction of the provided electrical current).

At block **904**, method **900** involves modulating the electrical current to adjust an orientation of the first platform about the axis of rotation to achieve a target orientation. By way of example, consider a scenario where sensor **312** is a gyroscope (e.g., direction) sensor mounted on platform **310**. In the scenario, a controller **314** (or **344**) may be configured to process outputs from sensor **312** and rotate platform **310** until sensor **312** measures a specific target change in direction (e.g., a value of zero, etc.). In this scenario, circuitry **350** can modulate the electrical current to cause platform **310** to rotate in a particular direction and/or speed opposite to a change in direction or speed measured by sensor **312**. Other scenarios are possible as well.

Thus, in some implementations, method **900** also involves modulating a characteristic of the rotation of the rotor platform (e.g., rate of rotation, acceleration of rotation, direction of rotation, etc.). Additionally or alternatively, in some implementations, method **900** also involves obtaining output of a magnetic field sensor (e.g., sensor **490**), and determining an orientation of the rotor platform about the axis of rotation based on the output of the magnetic field sensor, in line with the discussion above.

It should be understood that arrangements described herein are for purposes of example only. As such, those

skilled in the art will appreciate that other arrangements and other elements (e.g. machines, interfaces, functions, orders, and groupings of functions, etc.) can be used instead, and some elements may be omitted altogether according to the desired results. Further, many of the elements that are described are functional entities that may be implemented as discrete or distributed components or in conjunction with other components, in any suitable combination and location, or other structural elements described as independent structures may be combined.

While various aspects and embodiments have been disclosed herein, other aspects and embodiments will be apparent to those skilled in the art. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope being indicated by the following claims, along with the full scope of equivalents to which such claims are entitled. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting.

What is claimed is:

1. A device comprising:

a first platform having a first side;

a second platform having a second side that at least partially overlaps the first side of the first platform, wherein the first side remains within a predetermined distance to the second side in response to rotation of the first platform about an axis of rotation of the first platform;

a plurality of magnets mounted to the first platform in a circular arrangement around the axis of rotation, wherein the plurality of magnets provides a first-platform magnetic field, wherein the plurality of magnets includes a first magnet that is magnetized in a first direction that is substantially parallel to the axis of rotation and a second magnet that is magnetized in a second direction opposite to the first direction;

a first electrically conductive path comprising a first coil extending around the axis of rotation;

a second electrically conductive path comprising a second coil extending around the axis of rotation, wherein the second coil is interleaved with the first coil, wherein the first and second electrical paths comprise:

a first plurality of conductive structures included in the second platform in a first substantially coplanar arrangement;

a second plurality of conductive structures included in the second platform in a second substantially coplanar arrangement that is substantially parallel to the first substantially coplanar arrangement of the first plurality of conductive structures; and

a plurality of electrical contacts that electrically couple the first plurality of conductive structures to the second plurality of conductive structures; and

circuitry that causes a first electrical current to flow through the first electrically conductive path via a first lead and a second lead and a second electrical current to flow through the second electrically conductive path via a third lead and a fourth lead, wherein the first and second electrical currents generate a second-platform magnetic field that interacts with the first-platform magnetic field such that the first platform rotates about the axis of rotation.

2. The device of claim 1, wherein the second magnet is adjacent to the first magnet.

3. The device of claim 1, wherein the first plurality of conductive structures is at a first distance to the plurality of

magnets, and wherein the second plurality of conductive structures is at a second distance to the plurality of magnets.

4. The device of claim 1, wherein the device further comprises a circuit board, wherein the first plurality of conductive structures are disposed in a first layer of the circuit board, wherein the second plurality of conductive structures are disposed in a second layer of the circuit board, and wherein the plurality of electrical contacts comprise electrical connections between the first layer and the second layer.

5. The device of claim 1, wherein the first plurality of conductive structures includes a plurality of spaced-apart conductive structures that are spaced apart by a substantially uniform distance.

6. The device of claim 5, wherein the first plurality of conductive structures further comprises first and second adjacent conductive structures that are spaced apart by a distance that is greater than the substantially uniform distance, the device further comprising:

a magnetic field sensor included in the second platform between the first and second adjacent conductive structures, wherein the magnetic field sensor provides an output that is indicative of one or more characteristics of the first-platform magnetic field at a position of the magnetic field sensor, and wherein the circuitry determines an orientation of the first platform about the axis of rotation based on the output from the magnetic field sensor.

7. The device of claim 6, wherein the one or more characteristics comprises an angle of the first-platform magnetic field at the position of the magnetic field sensor.

8. The device of claim 1, wherein the plurality of magnets comprise an index magnet having a characteristic that differs from a corresponding characteristic of other magnets of the plurality of magnets.

9. The device of claim 8, wherein the index magnet is positioned at a first distance to the axis of rotation, and wherein the other magnets are positioned at a second distance to the axis of rotation.

10. The device of claim 8, wherein the index magnet has a first size, and wherein the other magnets have a second size that differs from the first size.

11. The device of claim 8, wherein the index magnet comprises magnetic material having a first magnetization strength, and wherein the other magnets comprise magnetic material having a second magnetization strength.

12. The device of claim 1, wherein the first electrically conductive path comprises a first structure of the first plurality of conductive structures and a second structure of the second plurality of conductive structures, wherein the second electrically conductive path comprises a third structure of the first plurality of conductive structures and a fourth structure of the second plurality of conductive structures.

13. The device of claim 12, wherein the first structure is adjacent the second structure and the third structure is adjacent the fourth structure.

14. The device of claim 1, wherein the first plurality of conductive structures are disposed between a first circle and a second circle concentric with the axis of rotation, and wherein the second plurality of conductive structures are disposed between a third circle and a fourth circle concentric with the axis of rotation.

15. The device of claim 14, wherein each conductive structure of the first plurality of conductive structures is tilted relative to a radius of the first circle, and wherein each structure of the second plurality of conductive structures is tilted relative to a radius of the third circle.

16. The device of claim 14, wherein a region between the first circle and the second circle at least partially overlaps the plurality of magnets.

\* \* \* \* \*