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**Biderman et al.**

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(54) **WHEEL SPOKING SYSTEMS AND METHODS OF MANUFACTURING AND INSTALLING WHEEL SPOKES**

(58) **Field of Classification Search**  
CPC .. B60B 1/00; B60B 1/003; B60B 1/02; B60B 1/04; B60B 1/0261; B60B 1/0269;  
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(71) Applicant: **Massachusetts Institute of Technology**, Cambridge, MA (US)

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(72) Inventors: **Assaf Biderman**, Boston, MA (US); **Carlo Ratti**, Turin (IT); **Christine Louise Outram**, West Hollywood, CA (US)

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(73) Assignee: **Massachusetts Institute of Technology**, Cambridge, MA (US)

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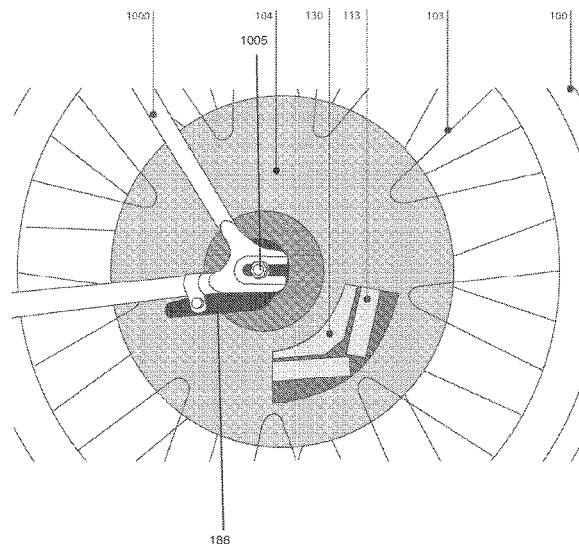
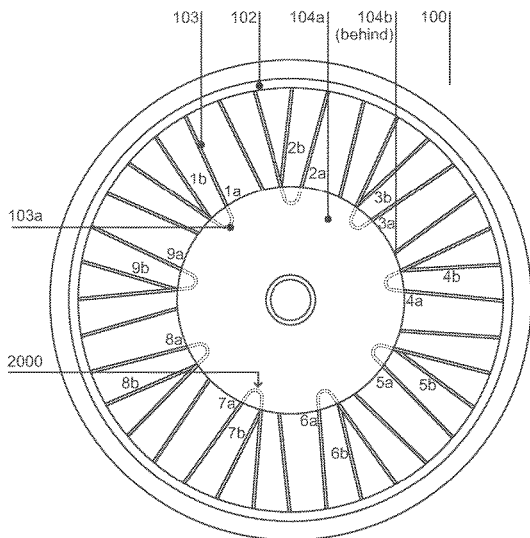
*Primary Examiner* — James M Dolak  
(74) *Attorney, Agent, or Firm* — GTC Law Group PC & Affiliates

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**B62M 6/60** (2010.01)  
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(57) **ABSTRACT**  
Embodiments of wheel spoking systems and methods of manufacturing and installing. An electrically motorized wheel can include a wheel rim, a wheel hub, and a plurality of wheel spokes connecting the wheel rim to the wheel hub wherein first and second ends of each of the plurality of wheel spokes are connected to the wheel rim and a curved portion of each of the plurality of wheel spokes interface with curved spoke pockets of the wheel hub.

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**25 Claims, 18 Drawing Sheets**



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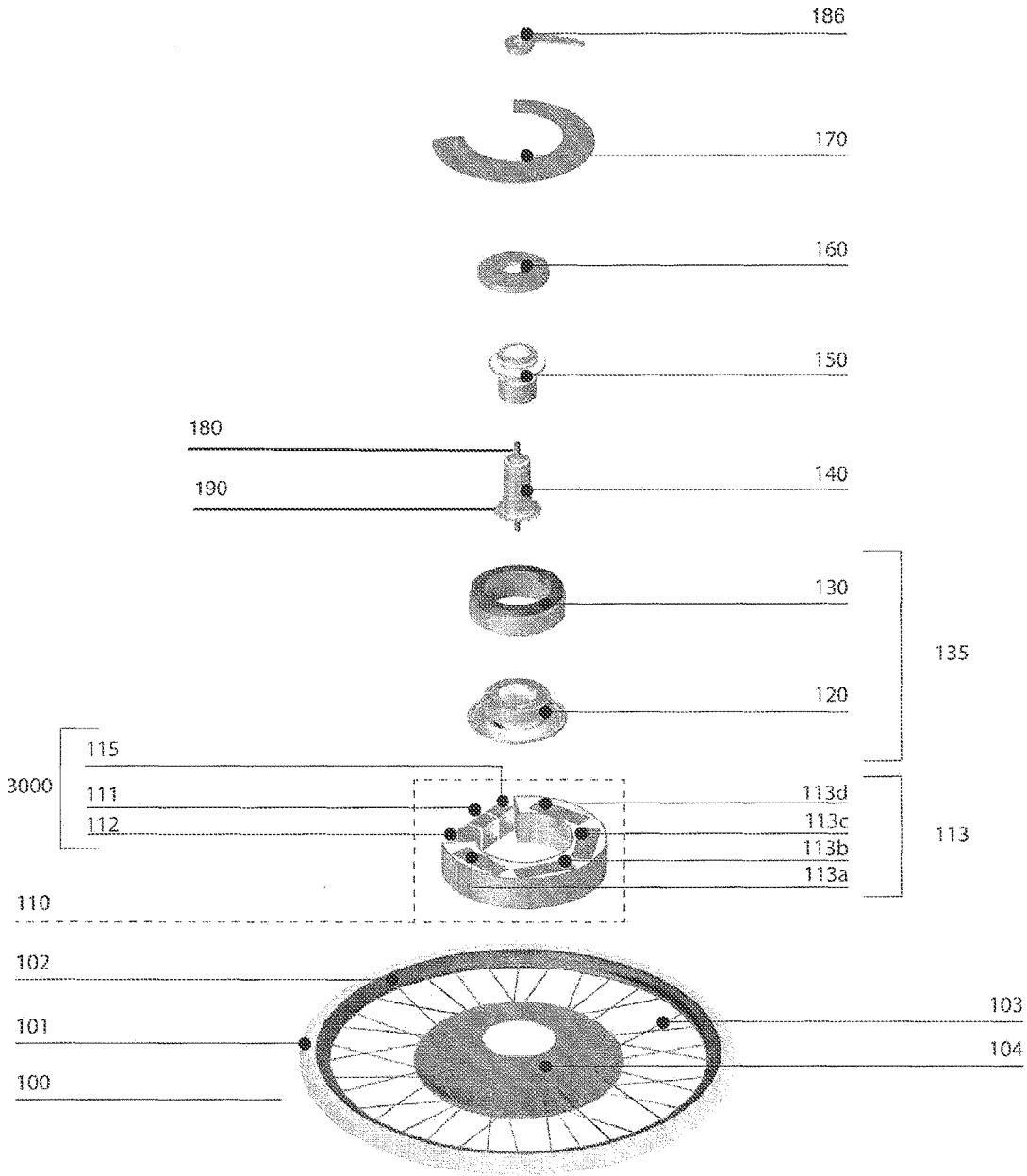


FIG. 1A

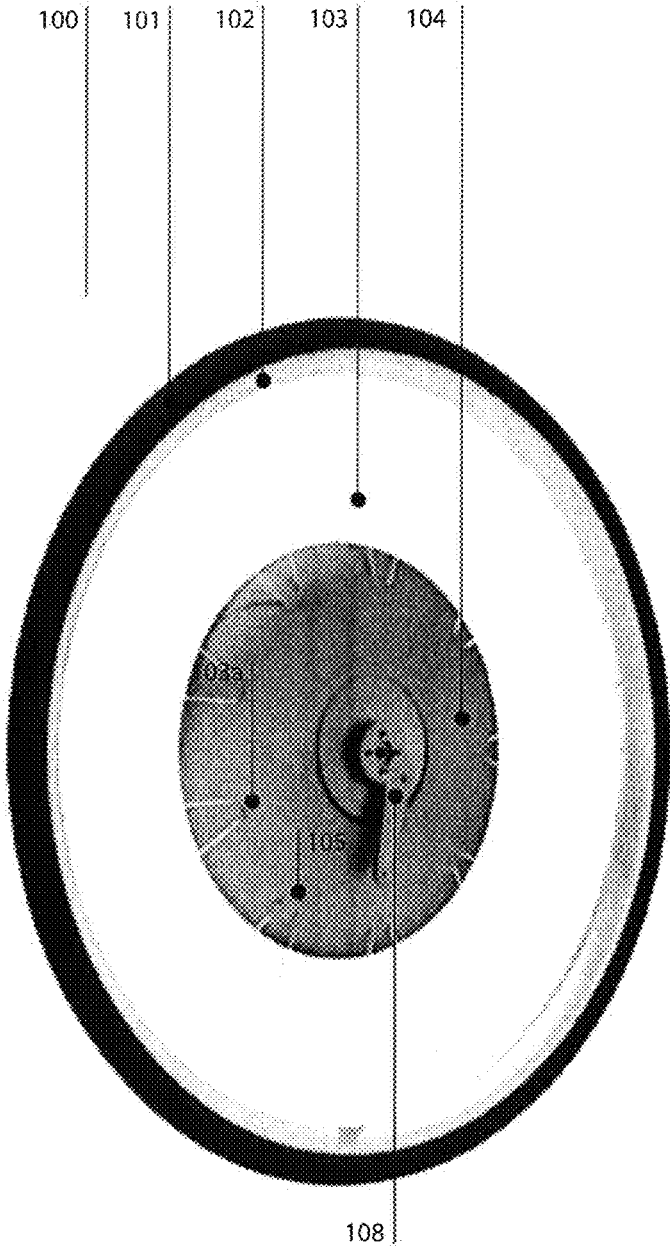


FIG. 1B

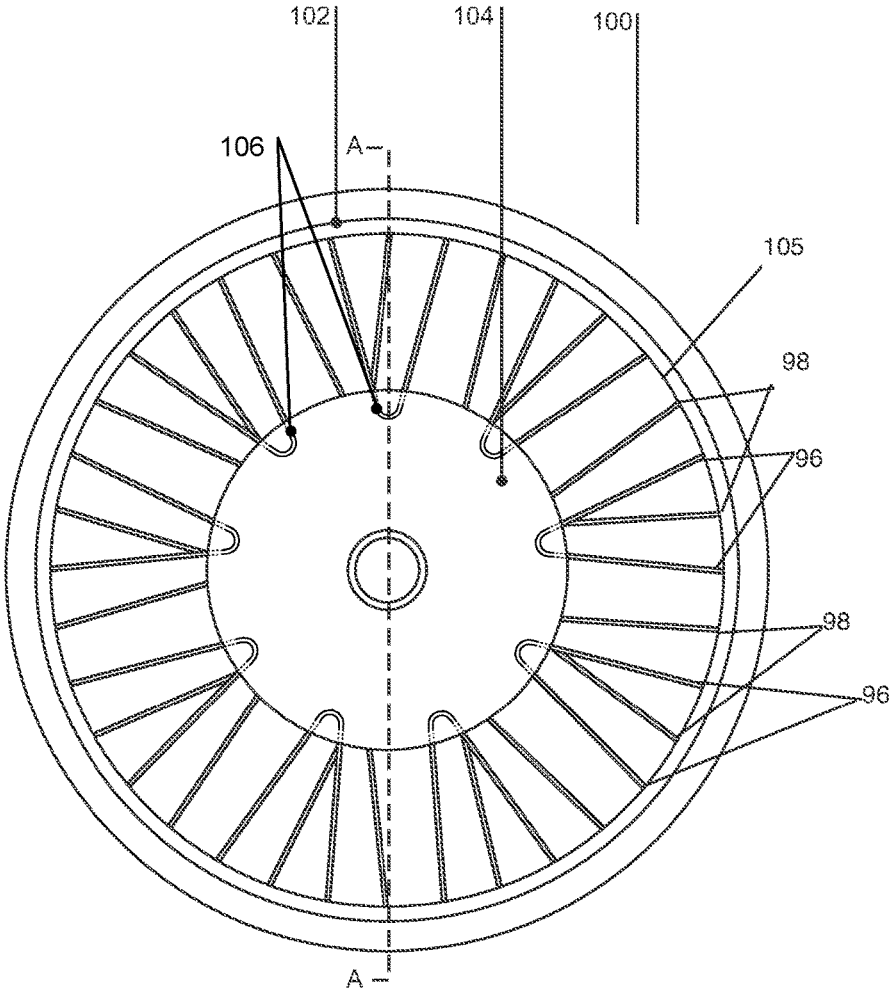


FIG. 2A

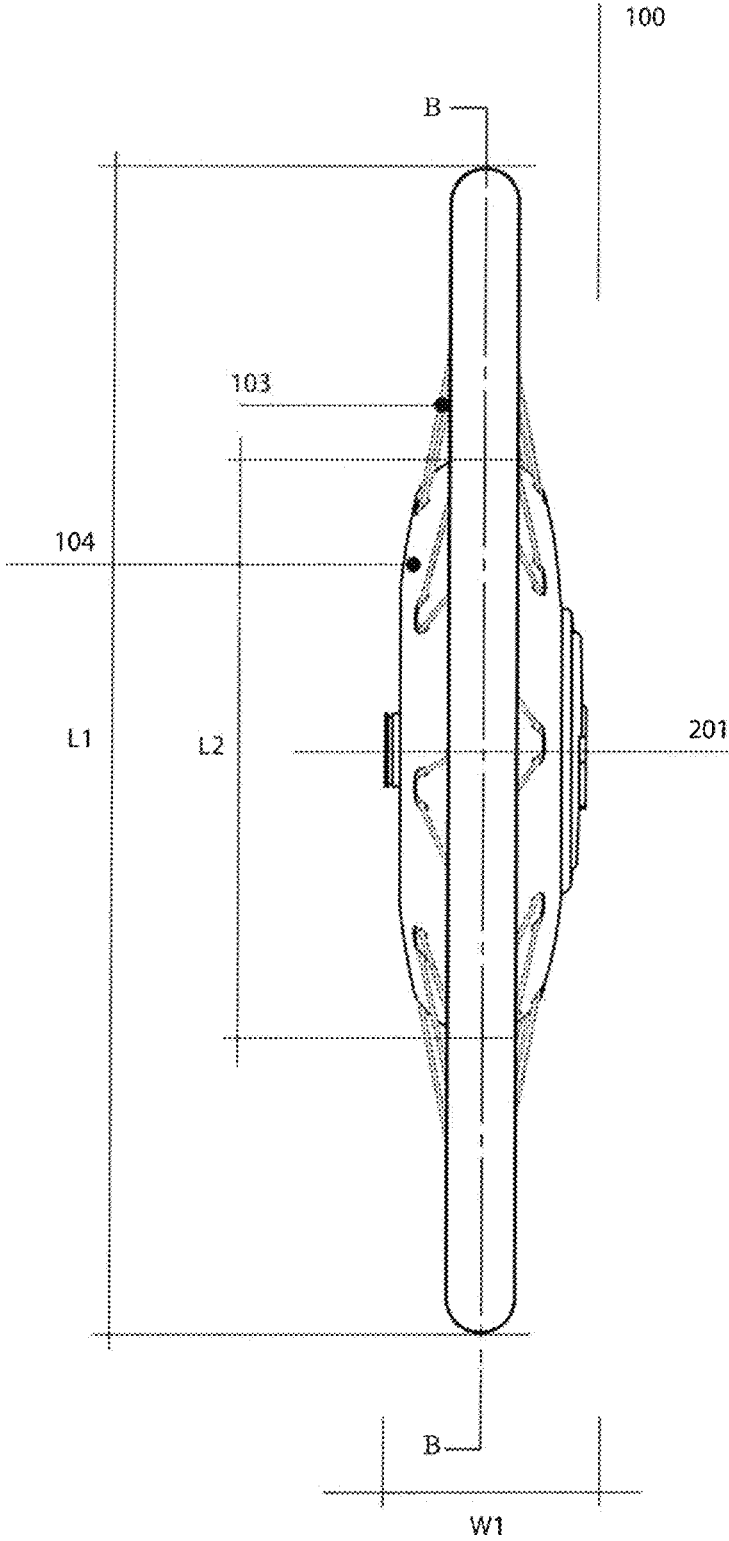
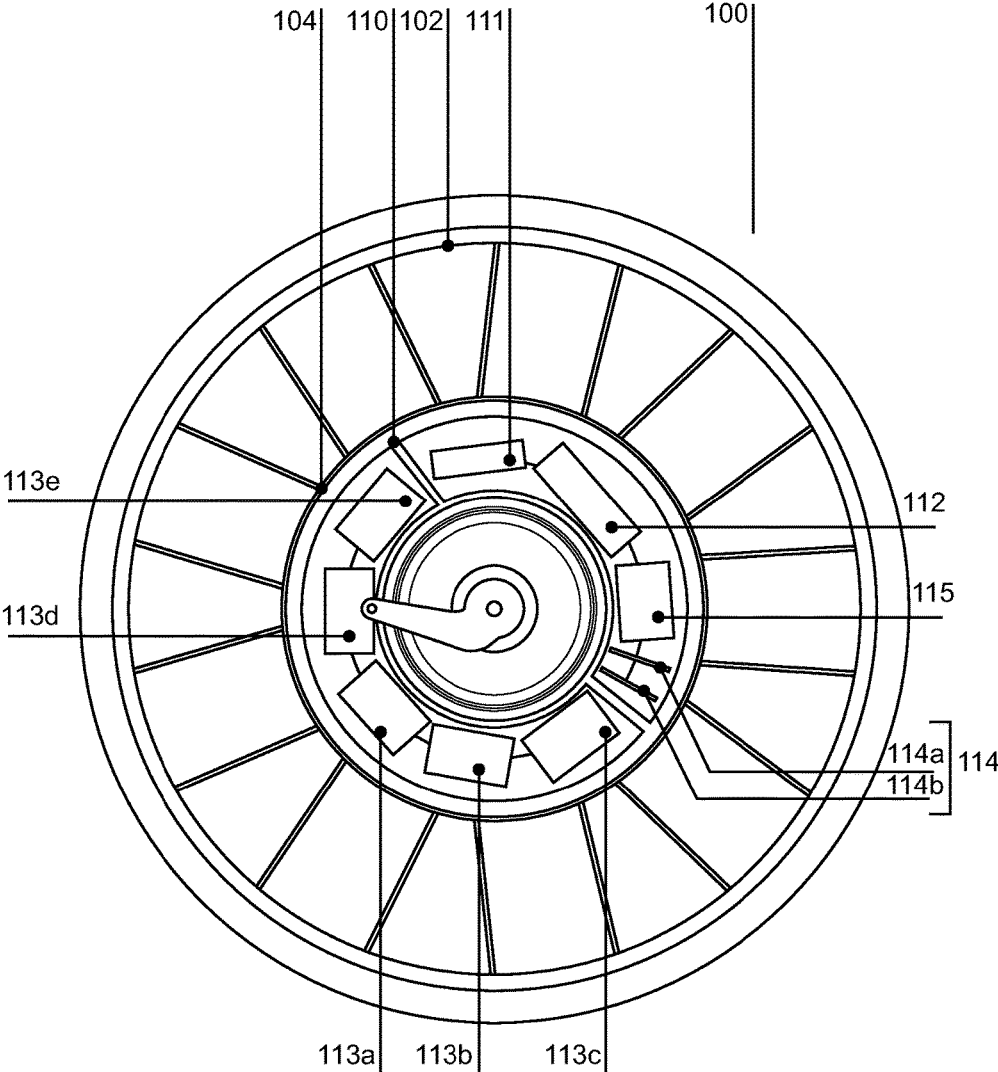


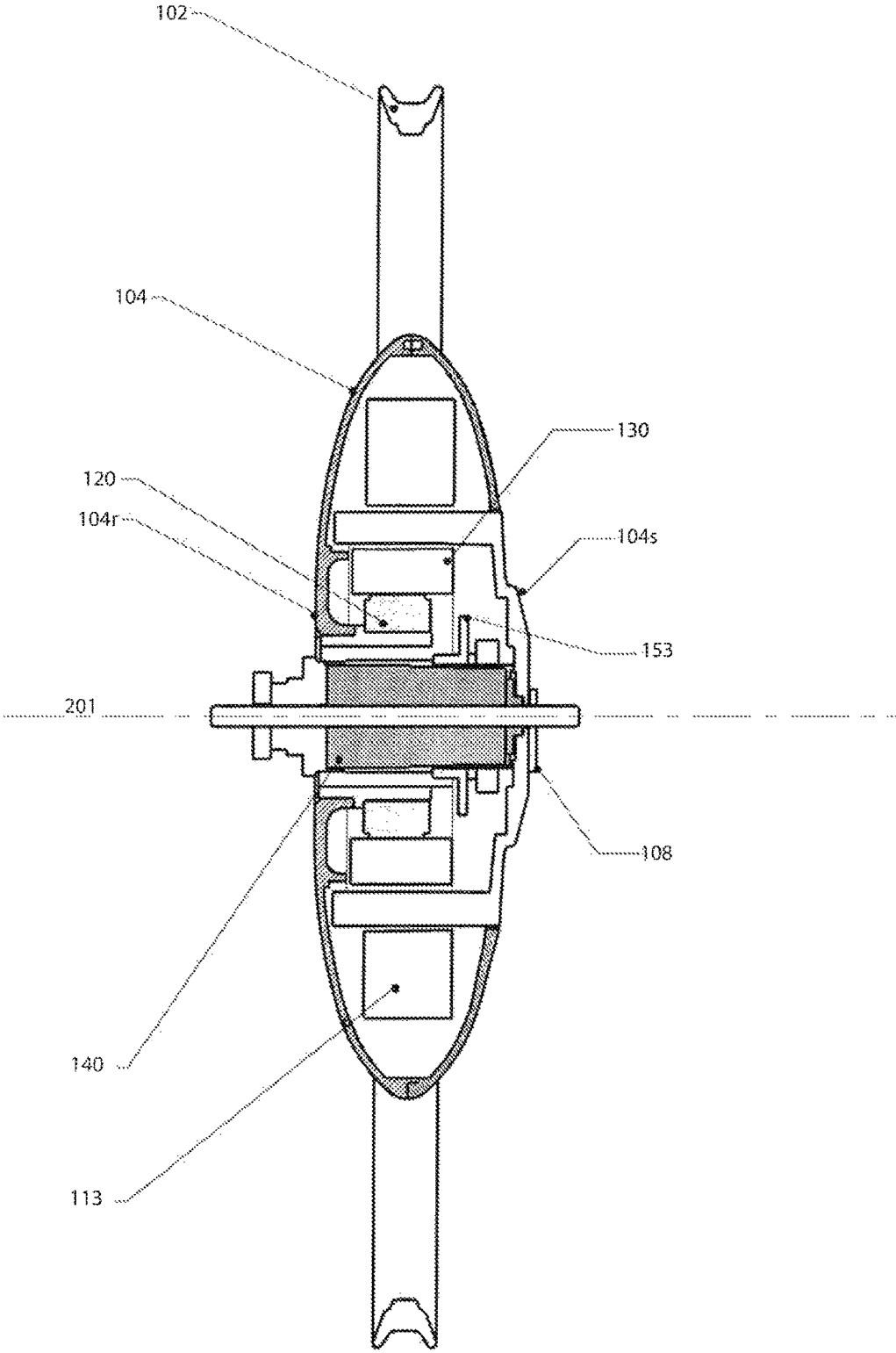
FIG. 2B





Section B-B'

FIG. 2C



Section A-A'

FIG. 3

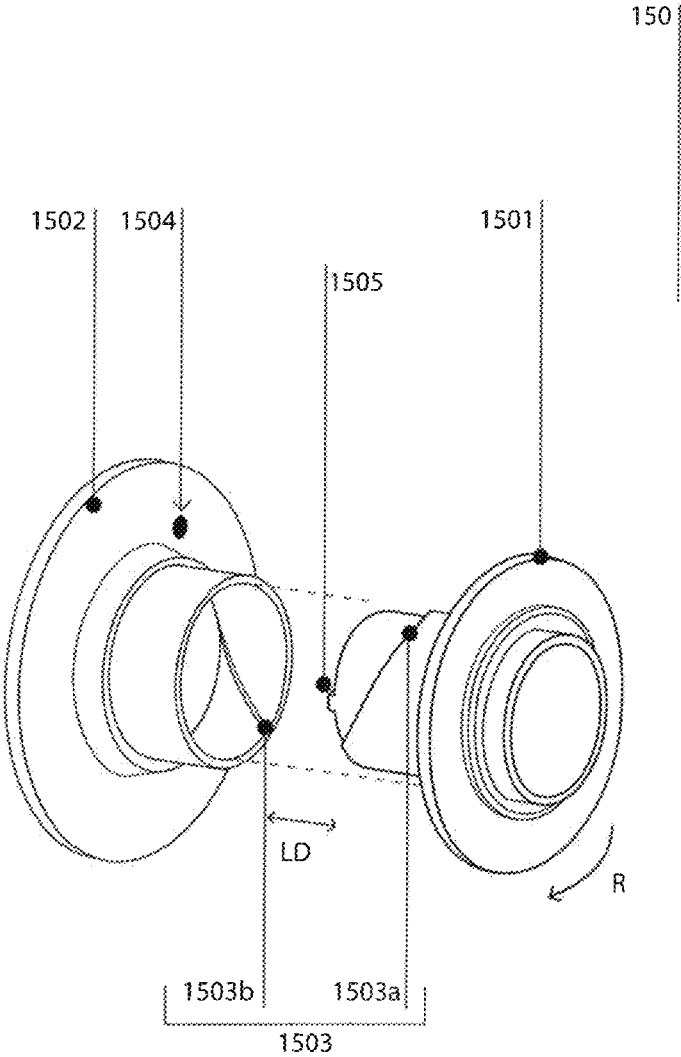


FIG. 4A

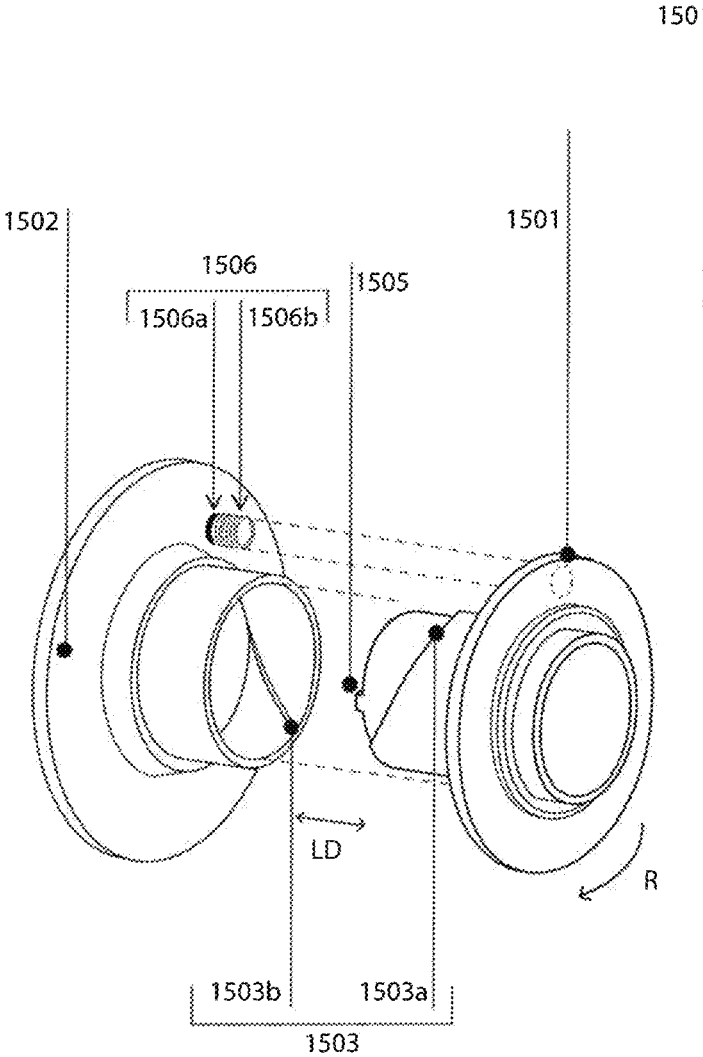


FIG. 4B

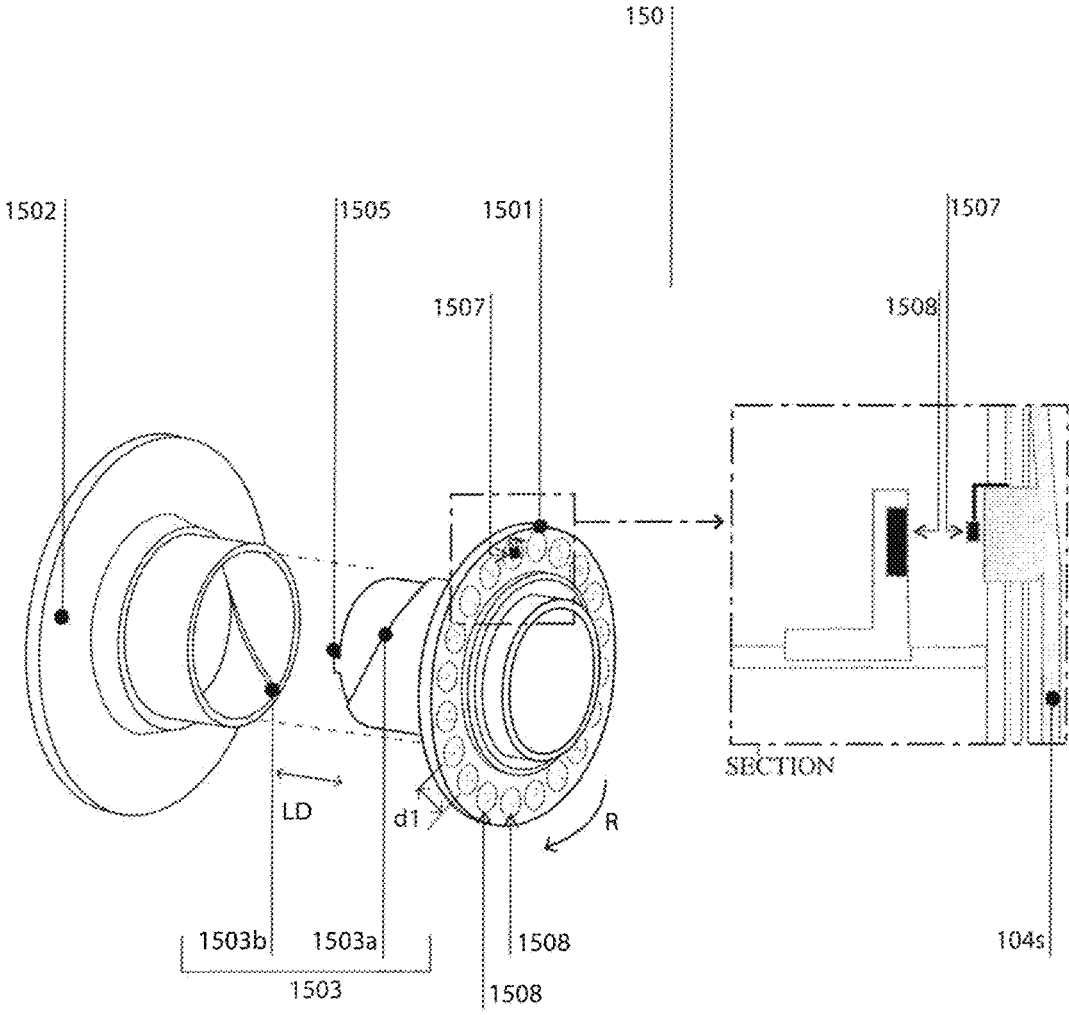


FIG. 4C

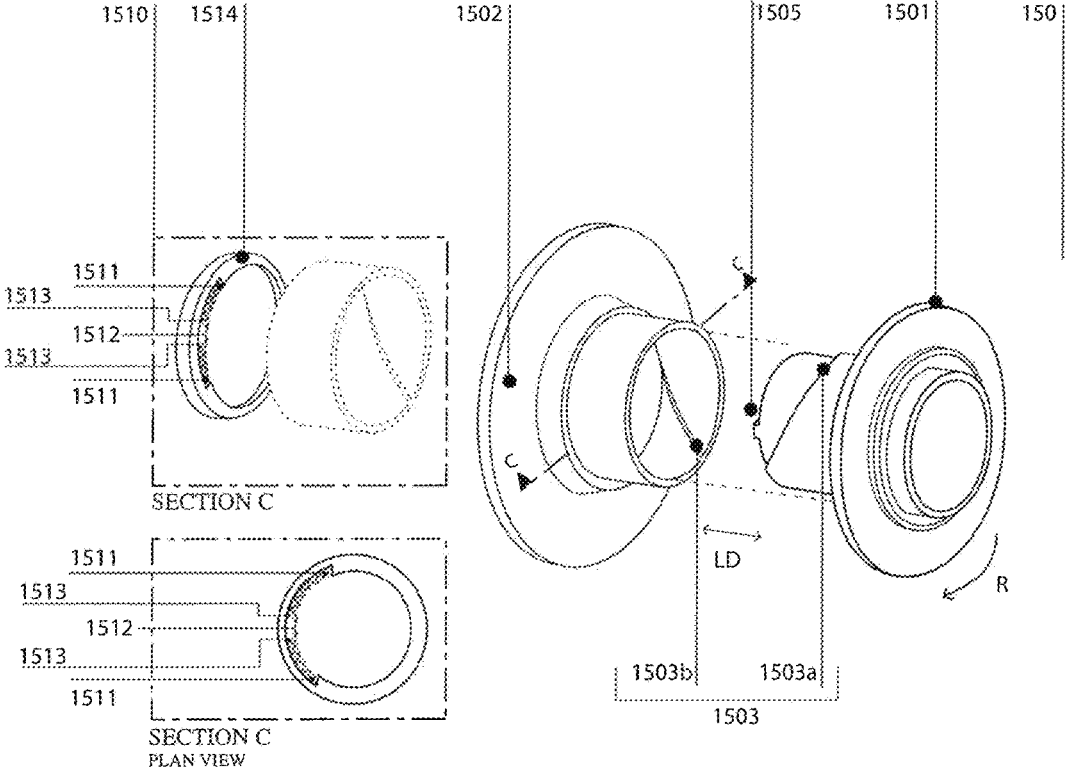
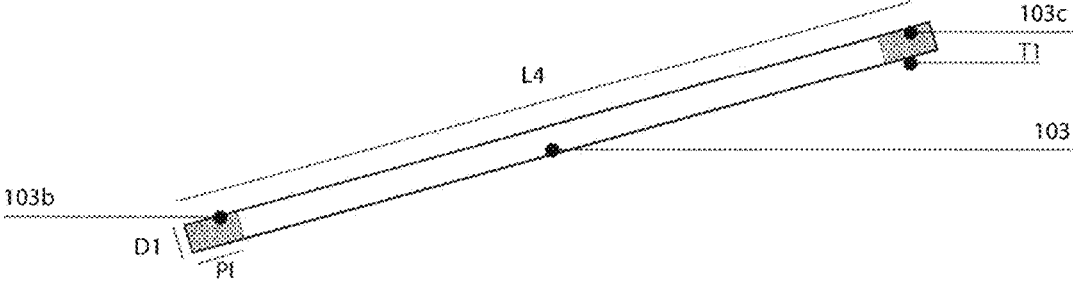


FIG. 4D



Spokes with two threaded ends.  
NOT TO SCALE

FIG. 5

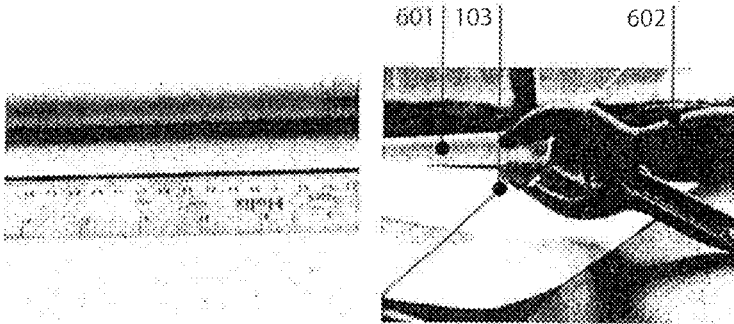


FIG. 6A

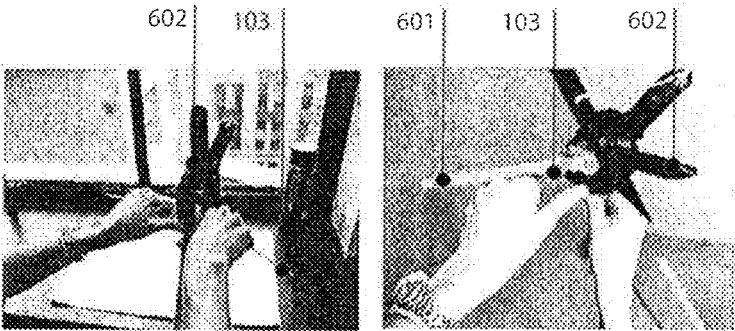


FIG. 6B

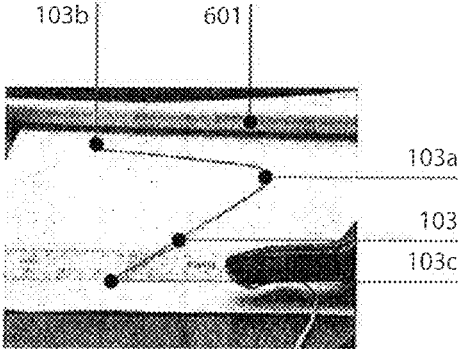


FIG. 6C



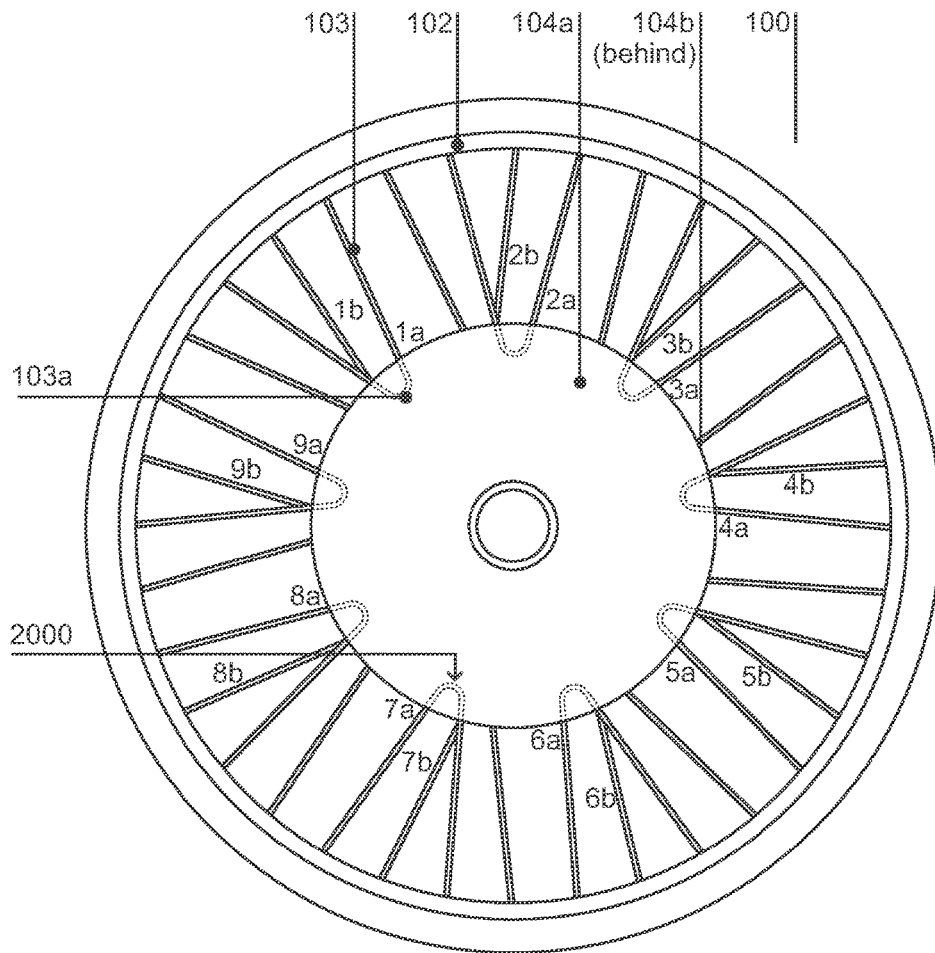


FIG. 7A

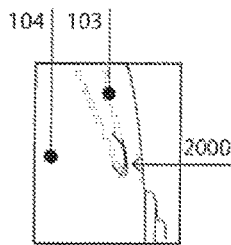


FIG. 7b

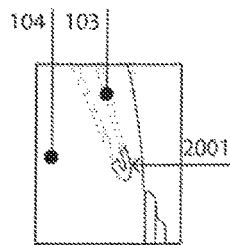


FIG. 7c

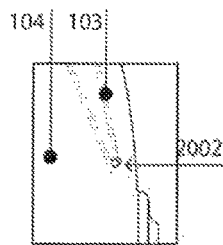


FIG. 7d

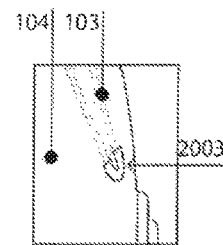


FIG. 7e

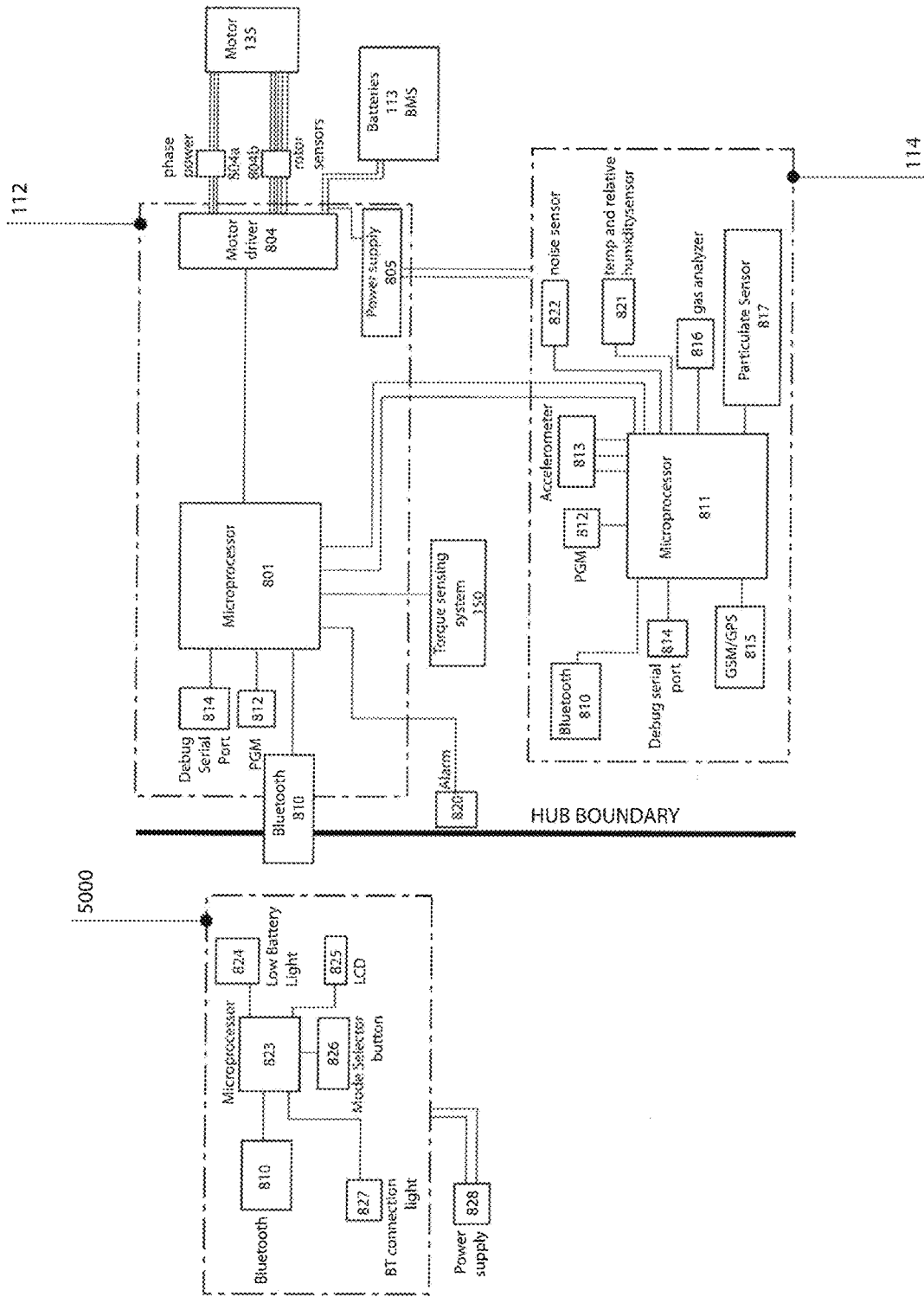


FIG. 8

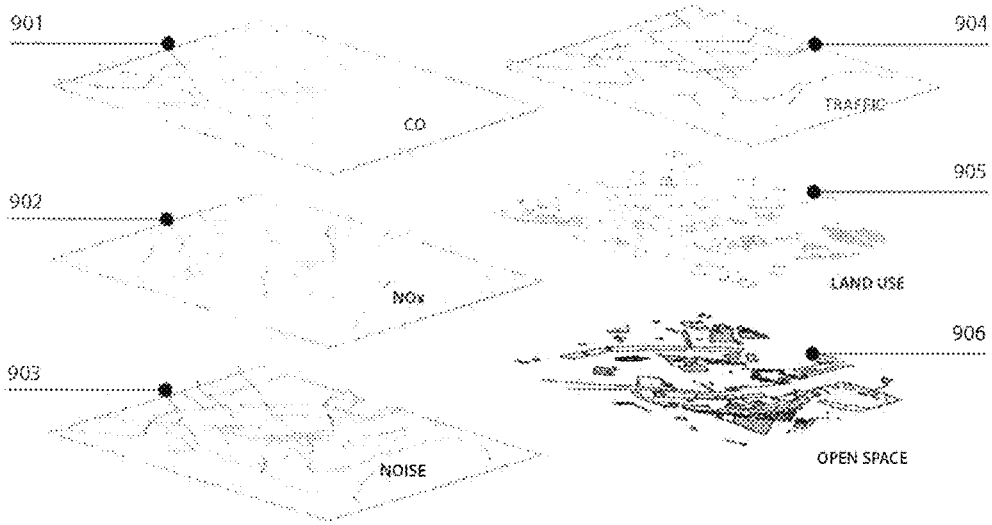


FIG. 9A

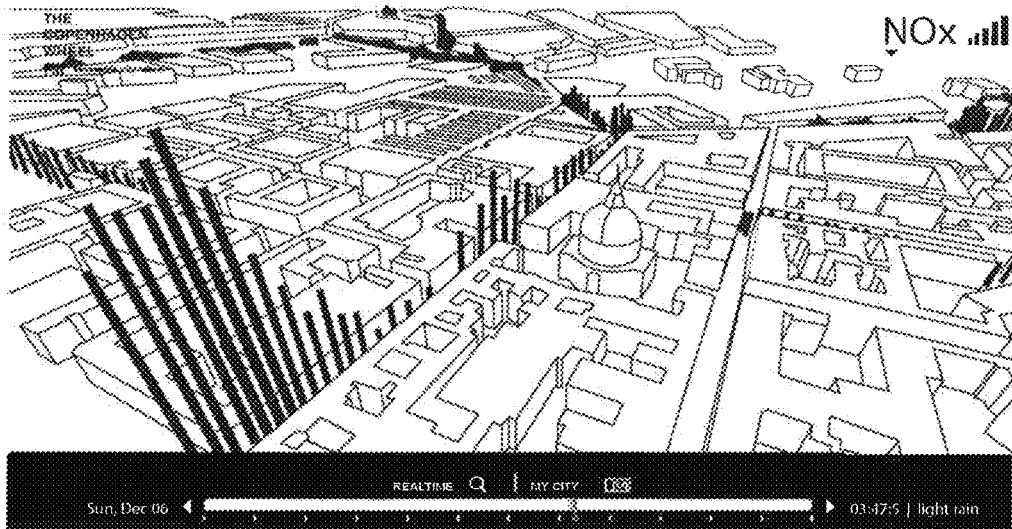


FIG. 9B

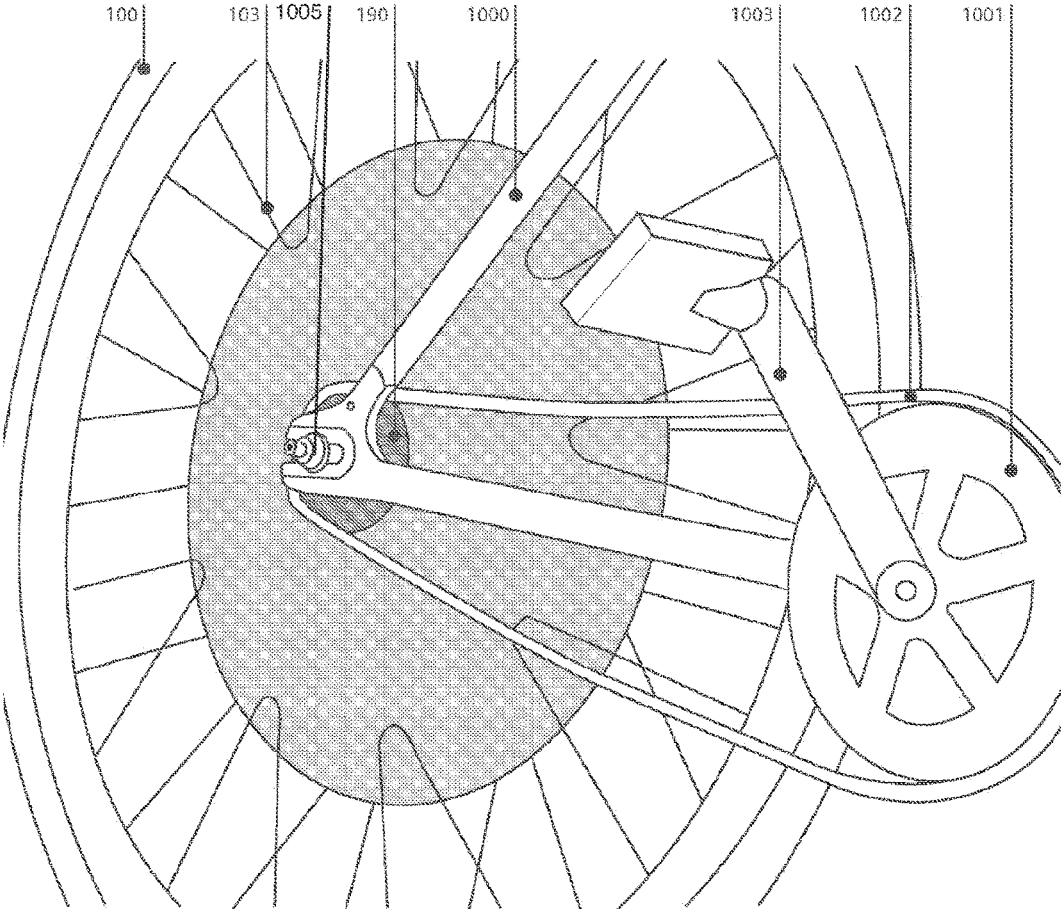


FIG. 10A

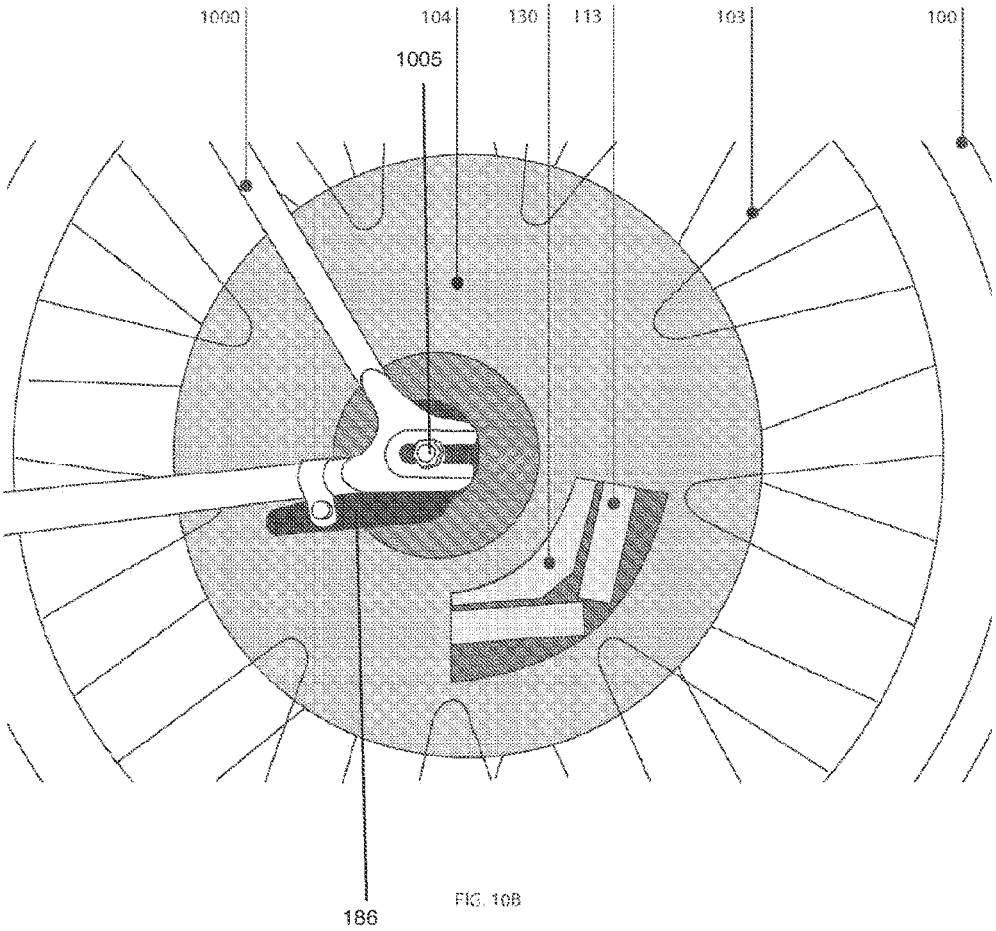


FIG. 10B

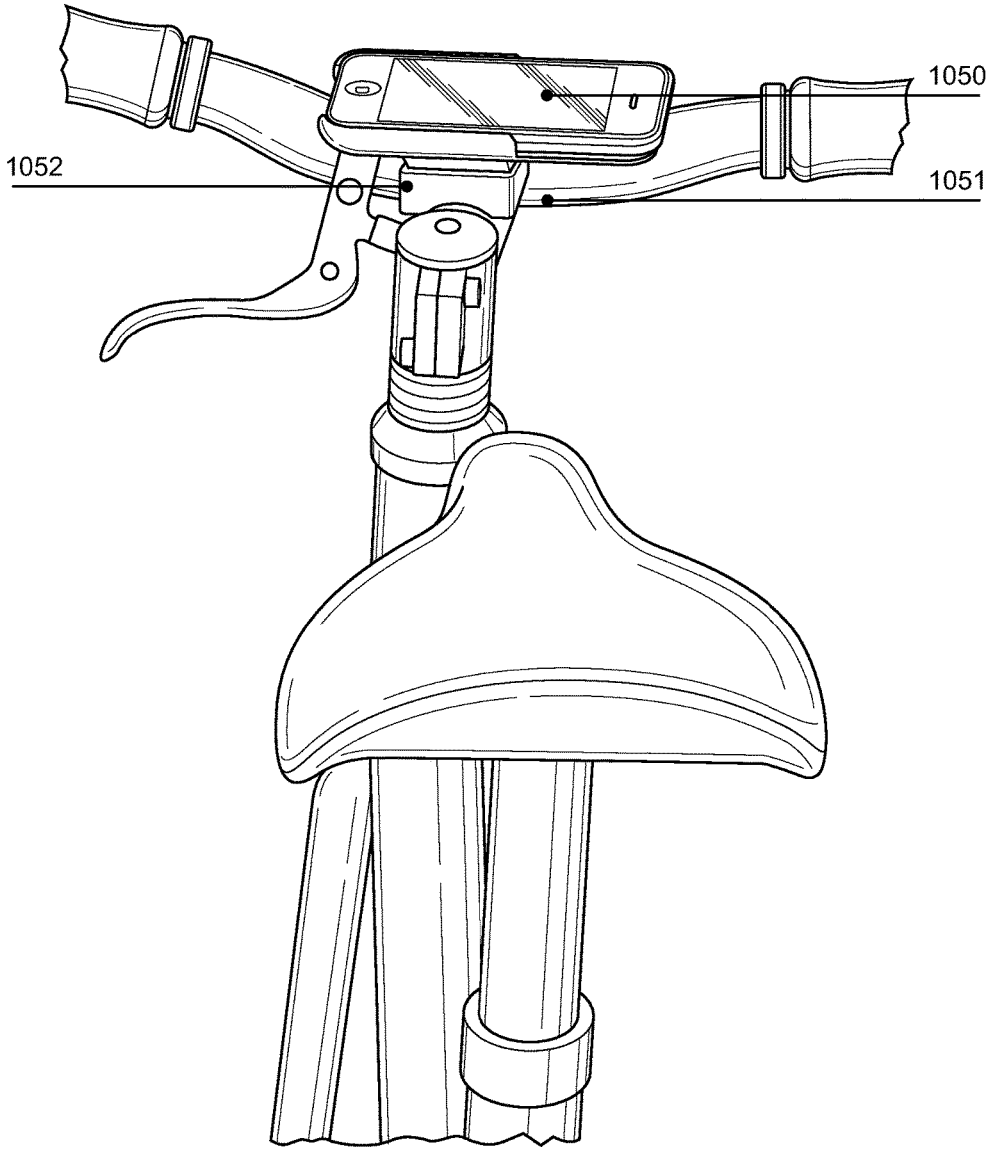


FIG. 10C

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# WHEEL SPOKING SYSTEMS AND METHODS OF MANUFACTURING AND INSTALLING WHEEL SPOKES

## RELATED APPLICATIONS

This application is a divisional of U.S. application Ser. No. 12/960,461, filed Dec. 3, 2010 and now issued as U.S. Pat. No. 9,027,681.

U.S. application Ser. No. 12/960,461 claims the benefit of U.S. Provisional Application No. 61/267,074, filed Dec. 6, 2009, U.S. Provisional Application No. 61/267,071, filed Dec. 6, 2009, and U.S. Provisional Application No. 61/266,862, filed Dec. 4, 2009.

## TECHNICAL FIELD

The present inventive concepts generally relate to hybrid sensor-enabled electric wheels, and more particularly, to hybrid sensor-enabled and autonomous electric wheels and associated systems, such as, energy regeneration systems, braking systems, torque sensing systems, control unit systems, and locking and alarm systems. The present inventive concepts further relate to multi-hub wheel spoking systems and methods of manufacturing and installing the same.

## BACKGROUND

According to some statistics, the global annual production of bicycles is roughly 100 million. At the present time, the industry appears to be experiencing steady growth, fueled in part by the increasing use of bicycles for recreation and urban transportation. In particular, electric bicycles, or e-bike usage worldwide also appears to be rapidly escalating as urban populations assess the environmental impact of fossil-fueled transportation and new regulations governing motorized transportation.

Conventional electric bicycles, or e-bikes, generally comprise an electric motor and a rechargeable battery pack, and can be separated into two categories: pedelec bicycles and all-electric bicycles. Pedelec bicycles generally comprise an electric motor that is activated only while a cyclist is pedaling, while on the other hand, all-electric bicycles can be operated solely on motorized power without pedaling.

As electric bicycle usage escalates, cyclists may wish to motorize their existing pedal bicycles. However, conventional electric conversion kits for bicycles generally comprise a large, bulky battery pack and an electric motor that are separately mounted from one another. As such, a wiring harness must be installed on the bicycle frame to provide electrical power from the battery pack to the electric motor, as well as additional wires for controlling the bike.

## SUMMARY

Embodiments of the present application are directed in part to hybrid sensor-enabled and autonomous electric wheels and associated systems that have diverse applications in the area of urban mobility. In particular, embodiments of hybrid sensor-enabled and autonomous electric wheels described herein can comprise a plurality of systems and devices integrated into a single compact hub unit that can be retrofitted into numerous types of wheeled vehicles. In this manner, the wheels described herein can be mounted to various types of bicycles or wheel vehicles in a 'plug and play' manner so as to turn existing conventional pedal

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bicycles or other wheeled vehicles into electric powered vehicles without a need to for additional wiring or components.

In some embodiments, the wheel can be controlled in response to a torque applied at the pedals of bicycle. In some embodiments, the wheel can be controlled in response to control commands transmitted from a wireless device, such as, a cellular telephone.

Embodiments of the present application are further directed to two-wheeled bicycles comprising a preinstalled hybrid sensor-enabled and autonomous electric wheel having a plurality of systems and devices integrated into a single compact hub unit.

Embodiments of hybrid sensor-enabled and autonomous electric wheels described herein can comprise an electric motor, one or more batteries or energy storing devices, a control unit and one or more optional sensor systems, such as location sensor systems and/or environmental sensor systems that can be integrated within a wheel hub of a hybrid sensor-enabled and autonomous electric wheel.

In some embodiments, the hybrid sensor-enabled and autonomous electric wheel can be fully controlled via bicycle pedals by sensing torque that is applied by a cyclist. For example, when a cyclist applies a positive torque to the wheel via bicycle pedals, the hybrid sensor-enabled and autonomous electric wheel supplements the positive torque applied by the cyclist by a predetermined amount. That is, for example, an electric motor of the wheel provides a predetermined amount of positive torque in addition to the torque applied by the cyclist. In another example, when a cyclist applies negative torque (e.g., activates a pedal brake, back-pedals) the hybrid sensor-enabled and autonomous electric wheel supplements the negative torque applied by the cyclist. That is, for example, an electric motor of the wheel generates a supplemental negative torque. In some embodiments, the energy generated by the supplemental negative torque is transferred and/or stored in one or more batteries or energy storing devices of the wheel.

In some embodiments, a smartphone can be configured to communicate with the hybrid sensor-enabled and autonomous electric wheel via Bluetooth, or other wireless protocol, and can access and receive various types of data collected by sensors of the wheel. The smartphone can also be used to configure the data collection processes of the wheel. For example, the smartphone can configure a control unit and sensor systems of the wheel to collect various types of environmental and location data, which can be accessed and retrieved by the smartphone.

The smartphone can also be used to control operational modes of the hybrid sensor-enabled and autonomous electric wheel. For example, a cyclist can configure the wheel to operate in an energy regeneration mode or exercise mode such that an electric motor of the wheel generates and transfers electrical energy to one or more batteries or energy storing devices of the wheel while the cyclist is pedaling. The cyclist can further configure the magnitude of the predetermined amount of applied positive torque.

Embodiments of the present application are further directed to wheel spoking systems, methods of spoking wheels, and methods of manufacturing wheel spoking systems. A wheel spoking system can comprise a plurality of wheel spokes connected between a wheel rim and a wheel hub. In one embodiment, first and second ends of each of the plurality of wheel spokes are connected to the wheel rim, and a curved portion of each of the plurality of wheel spokes are connected to the wheel hub. For example, the curved portion of each of the plurality of wheel spokes can interface

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with curved spoke pockets of the wheel hub. In other embodiments, the curved portion of each of the plurality of wheel spokes can interface with hooks, fasteners and/or protrusions of the wheel hub.

In this manner, the systems and methods of wheel spoking described herein removes the requirement of a spoke flange on the wheel hub, and further provides a seamless connected between the wheels spokes and exterior surfaces of the wheel hub. Such systems and methods can provide for faster spoking of wheels over conventional systems and methods, and allows for greater variety of forms of wheel hubs.

In one aspect, an electrically motorized, retrofittable vehicle wheel, comprises: a motorized hub unit connected to a wheel rim; and a mechanical coupling mechanism constructed and arranged to secure the motorized hub unit to a non-motorized wheeled vehicle.

In some embodiments, the mechanical coupling mechanism is further constructed and arranged to wirelessly secure the motorized hub unit to a non-motorized wheeled vehicle.

In some embodiments, the non-motorized wheeled vehicle comprises a bicycle.

In some embodiments, the motorized hub unit comprises: an electric motor; a control unit configured to control a drive torque of the electric motor; and a power source electrically connected to the control unit and the electric motor.

In some embodiments, the electric motor, the control unit and the power source are provided within an outer casing of the motorized hub unit.

In some embodiments, the wheel further comprises a torque sensor configured to determine a torque applied to a sprocket of the motorized wheel hub, wherein the control unit adjusts a drive torque of the electric motor in response to the applied torque.

In some embodiments, the control unit adjusts a drive torque of the electric motor in response to a command signal wirelessly received from a wireless control unit or a cell phone.

In another aspect, an electrically motorized bicycle wheel, comprises: a wheel rim;

a wheel hub, including: an electric motor; a battery pack; and a control unit configured to control a drive torque of the electric motor; and a plurality of wheel spokes connecting the wheel rim to the wheel hub, wherein the electric motor, the battery pack and the control unit are positioned within the wheel hub.

In some embodiments, the electric motor comprises a frameless rotary motor.

In some embodiments, the electric motor comprises a rotor and a stator.

In some embodiments, the battery pack comprises a plurality of rechargeable battery cells.

In some embodiments, the plurality of rechargeable battery cells comprise a plurality of lithium polymer batteries.

In some embodiments, the battery pack comprises at least two parallel-connected sets of at least two series-connected rechargeable batteries.

In some embodiments, the at least two parallel-connected sets of at least two series-connected rechargeable batteries comprises three parallel-connected sets of six series-connected rechargeable batteries.

In some embodiments, the battery pack is removable from the wheel hub.

In some embodiments, the wheel hub further includes a wheel hub gear system.

In some embodiments, the wheel hub gear system comprises an automatic shifting gear system.

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In some embodiments, the automatic shifting gear system comprises a 3-speed automatic shifting gear system.

In some embodiments, the wheel hub gear system comprises a manual shifting gear system.

In some embodiments, the wheel hub gear system is partially positioned within the wheel hub.

In some embodiments, the wheel hub gear system comprises at least one gear sprocket constructed and arranged to engage a bicycle chain.

In some embodiments, the bicycle chain is arranged to engage a pedal sprocket, and wherein the pedal sprocket is connected to bicycle pedals.

In some embodiments, a cyclists torque applied to the bicycle pedals is transferred to the at least one gear sprocket of the wheel hub gear system.

In some embodiments, the wheel hub further includes a coaster brake connected to the wheel hub gear system.

In some embodiments, the coaster brake is constructed and arranged to be secured to a bicycle frame.

In some embodiments, mechanical braking occurs through the coaster brake and the inner wheel hub gear system.

In some embodiments, mechanical braking is activated in response to back-pedaling.

In some embodiments, first and second ends of each of the plurality of wheel spokes are connected to the wheel rim, and a curved portion of each of the plurality of wheel spokes interface with curved spoke pockets of the wheel hub.

In some embodiments, the curved spoke pockets are formed in external side surfaces of the wheel hub.

In some embodiments, the curved portion of each of the plurality of wheel spokes is positioned at a mid-point of each of the plurality of wheel spokes.

In some embodiments, wherein an angle of the plurality of wheel spokes ranges between about 20 degrees and about 60 degrees.

In some embodiments, a vertex of the angle is formed at the curved portion of each of the plurality of wheel spokes.

In some embodiments, the angle of the plurality of wheel spokes is about 40 degrees.

In some embodiments, the plurality of wheel spokes comprises a first set of wheel spokes and a second set of wheel spokes.

In some embodiments, first and second ends of the wheel spokes of the first and second sets are connected to the wheel rim, a curved portion of each of the wheel spokes of the first set interface with curved spoke pockets on a first external side surface of the wheel hub, and a curved portion of each of the wheel spokes of the second set interface with curved spoke pockets on a second external side surface of the wheel hub.

In some embodiments, the wheel spokes of the first and second sets are alternately connected around an inner circumference of the wheel rim.

In some embodiments, the wheel hub further includes a removable battery cover.

In some embodiments, the wheel hub comprises a milled aluminum wheel hub.

In some embodiments, the wheel hub comprises a rotating unit and a static unit.

In some embodiments, the rotating unit rotates in relation to the wheel rim.

In some embodiments, the plurality of wheel spokes are connected to external side surfaces of the rotating unit.

In some embodiments, a stator of the electric motor is secured to the static unit.



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In some embodiments, a rotor of the electric motor is secured to the rotating unit.

In another aspect, an electrically motorized bicycle wheel, comprises: a wheel rim; a wheel hub, including: an electric motor having a rotor and a stator; a wheel hub gear system connected to one of the rotor and the stator; a torque sensing system; a battery pack; and a control unit configured to control a drive torque of the electric motor; and a plurality of wheel spokes connecting the wheel rim to the wheel hub, wherein the electric motor, the torque sensing system, the battery pack and the control unit are positioned within the wheel hub.

In some embodiments, the torque sensing system is constructed and arranged to measure a cyclist torque applied to the wheel hub gear system.

In some embodiments, the torque sensing system is constructed and arranged to measure a rotational velocity of the wheel hub gear system.

In some embodiments, the wheel hub gear system comprises an automatic shifting gear system.

In some embodiments, the automatic shifting gear system comprises a 3-speed automatic shifting gear system.

In some embodiments, the wheel hub gear system comprises a manual shifting gear system.

In some embodiments, the wheel hub gear system is partially positioned within the wheel hub.

In some embodiments, the wheel hub gear system comprises at least one gear sprocket arranged to engage a bicycle chain.

In some embodiments, the torque sensing system comprises an inner sleeve secured to the wheel hub gear system.

In some embodiments, the inner sleeve is welded on to the wheel hub gear system.

In some embodiments, the inner sleeve rotates in relation with the wheel hub gear system.

In some embodiments, the torque sensing system further comprises an outer sleeve and a proximity sensor.

In some embodiments, when a torque is applied to one of the inner and outer sleeves, the inner sleeve rotates in a clockwise or counterclockwise direction.

In some embodiments, the rotation of the inner sleeve causes a ramp of the inner sleeve to ride up or down a ramp of the outer sleeve.

In some embodiments, an interaction between the inner sleeve and the outer sleeve affect a lateral displacement of the inner sleeve with respect to the outer sleeve.

In some embodiments, the cyclist torque is obtained from a lateral displacement between the inner sleeve and the outer sleeve.

In some embodiments, the proximity sensor determines a lateral displacement between the inner sleeve and the outer sleeve.

In some embodiments, the torque sensing system comprises an inner sleeve, an outer sleeve and a displacement sensor.

In some embodiments, the displacement sensor comprises spring/elastomer and a pressure sensor.

In some embodiments, the spring/elastomer and the pressure sensor are provided on the outer sleeve.

In some embodiments, the torque sensing system comprises an inner sleeve, an outer sleeve and a velocity sensor, wherein the velocity sensor comprises a plurality of magnets provided in an alternating configuration on an outer surface of the inner sleeve and a hall effect sensor.

In some embodiments, the outer sleeve comprises a spring/elastomer mechanism, the spring/elastomer mechanism being provided in a cylindrical housing of the outer

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sleeve, and configured to provide a gap region so that a notch of the inner sleeve can be positioned in the gap region.

In another aspect, an electrically motorized bicycle wheel, comprises: a wheel rim; a wheel hub, including: an electric motor comprising a rotor and a stator; a wheel hub gear system connected to one of the rotor and the stator; a battery pack; and a control unit configured to control a drive torque of the electric motor in response to a cyclist torque applied to the wheel hub gear system; and a plurality of wheel spokes connecting the wheel rim to the wheel hub, wherein the electric motor, the battery pack and the control unit are positioned within the wheel hub.

In some embodiments, when a cyclist applies a positive torque to the wheel hub gear system via bicycle pedals, the control unit commands the electric motor to supplement the positive torque applied by the cyclist by a predetermined amount.

In some embodiments, when a cyclist applies a negative torque to the wheel hub gear system via bicycle pedals, the control unit commands the electric motor to generate a negative torque on the wheel hub gear system.

In some embodiments, the electric motor is configured as a generator when generating the negative torque on the wheel hub gear system.

In some embodiments, energy generated by the electric motor when generating the negative torque is transferred to and stored in the battery pack.

In some embodiments, the wheel hub gear system comprises an automatic shifting gear system.

In some embodiments, the automatic shifting gear system comprises a 3-speed automatic shifting gear system.

In some embodiments, the wheel hub gear system comprises a manual shifting gear system.

In some embodiments, the wheel hub gear system is partially positioned within the wheel hub.

In some embodiments, the wheel hub gear system comprises at least one gear sprocket arranged to engage a bicycle chain.

In some embodiments, the control unit comprises at least one environmental sensor system.

In some embodiments, the at least one environmental sensor system comprises at least one sensor system selected from the group consisting of: a gas analyzer, a particulate sensor, a temperature sensor, a humidity sensor, and a noise sensor.

In some embodiments, the control unit is configured to collect and store environmental sensor system data.

In some embodiments, the control unit further comprises a telecommunications system unit that can access mobile/cellular data networks.

In some embodiments, the control unit is further configured to transmit environmental sensor system data to one or more internet connected system via the mobile/cellular data networks.

In some embodiments, the control unit comprises a global positioning system unit that can receive location and time data.

In another aspect, a method of fabricating a wheel spoke, comprises: clamping a spoke between a cylindrical roller and a clamping device; and bending the spoke at a mid-point around the cylindrical roller, wherein the resulting bent spoke has an angle between about 20 degrees and about 60 degree, a vertex of the angle being formed at the mid-point of the spoke.

In some embodiments, the cylindrical roller comprises a PVC pipe.

In some embodiments, the cylindrical roller comprises a metal pipe.

In some embodiments, the cylindrical roller comprises solid roller.

In some embodiments, the clamp comprises a screw clamp.

In some embodiments, the clamp comprises an industrial clip.

In some embodiments, the clamp comprises a pair of pliers.

In some embodiments, first and second ends of the spoke are threaded.

In another aspect, a wheel, comprises: a wheel rim; a wheel hub exclusive of a spoke flange; and a plurality of curved wheel spokes, threaded at both ends, connecting the wheel rim to the wheel hub.

In some embodiments, first and second ends of each of the plurality of wheel spokes are connected to the wheel rim, and a curved portion of each of the plurality of wheel spokes interface with curved spoke pockets of the wheel hub.

In some embodiments, the curved spoke pockets are formed in external side surfaces of the wheel hub.

In some embodiments, the curved portion of each of the plurality of wheel spokes is positioned at a mid-point of each of the plurality of wheel spokes.

In some embodiments, an angle of the plurality of wheel spokes ranges between about 20 degrees and about 60 degrees.

In some embodiments, a vertex of the angle is formed at the curved portion of each of the plurality of wheel spokes.

In some embodiments, the angle of the plurality of wheel spokes is about 40 degrees.

In some embodiments, the plurality of wheel spokes comprises a first set of wheel spokes and a second set of wheel spokes.

In some embodiments, first and second ends of the wheel spokes of the first and second sets are connected to the wheel rim, a curved portion of each of the wheel spokes of the first set interface with curved spoke pockets on a first external side surface of the wheel hub, and a curved portion of each of the wheel spokes of the second set interface with curved spoke pockets on a second external side surface of the wheel hub.

In some embodiments, the wheel spokes of the first and second sets are alternately connected around an inner circumference of the wheel rim.

In some embodiments, first and second ends of each of the plurality of wheel spokes are connected to the wheel rim, and a curved portion of each of the plurality of wheel spokes interface with an enclosed channel provided within an outer casing of the wheel hub.

In some embodiments, first and second ends of each of the plurality of wheel spokes are connected to the wheel rim, and a curved portion of each of the plurality of wheel spokes interface with protrusions or hooks extending outward from an outer casing of the wheel hub.

In some embodiments, first and second ends of each of the plurality of wheel spokes are connected to the wheel rim, and a curved portion of each of the plurality of wheel spokes interface with an external claps of the wheel hub.

In some embodiments, the motorized hub unit is connected to the wheel rim via a plurality of wheel spokes.

In some embodiments, the wheel spokes are under one of tension and compression.

In some embodiments, the motorized hub unit is connected to the wheel rim via a mesh material.

In some embodiments, the motorized hub unit is connected to the wheel rim via a disk.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features and advantages of embodiments of the present inventive concepts will be apparent from the more particular description of preferred embodiments, as illustrated in the accompanying drawings in which like reference characters refer to the same elements throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the preferred embodiments.

FIG. 1A is an exploded diagram of a hybrid sensor-enabled electric wheel, in accordance with embodiments of the present inventive concepts.

FIG. 1B is a perspective view of a hybrid sensor-enabled electric wheel, in accordance with embodiments of the present inventive concepts.

FIGS. 2A-2C are plan and section views of a hybrid sensor-enabled electric wheel, in accordance with embodiments of the present inventive concepts.

FIG. 3 is a cross-sectional view of the hybrid sensor-enabled electric wheel of FIG. 2A taken along lines A-A', in accordance with embodiments of the present inventive concepts.

FIG. 4A is a perspective view of a torque sensing system for hybrid sensor-enabled electric wheels, in accordance with embodiments of the present inventive concepts.

FIG. 4B is a perspective view of a torque sensing system for hybrid sensor-enabled electric wheels, in accordance with embodiments of the present inventive concepts.

FIG. 4C is a perspective view of a torque sensing system for hybrid sensor-enabled electric wheels, in accordance with embodiments of the present inventive concepts.

FIG. 4D illustrates several views of a spring/elastomer mechanism of a torque sensing system for hybrid sensor-enabled electric wheels, in accordance with embodiments of the present inventive concepts.

FIG. 5 is perspective view of a wheel spoke, in accordance with embodiments of the present inventive concepts.

FIGS. 6A-6C illustrate a method of manufacturing a wheel spoke, in accordance with embodiments of the present inventive concepts.

FIGS. 7A-7E illustrate wheel spoke configurations, in accordance with embodiments of the present inventive concepts.

FIG. 8 is a block diagram of a control and sensor system and a motor controller for a hybrid sensor-enabled electric wheel, in accordance with embodiments of the present inventive concepts.

FIGS. 9A and 9B are 3-dimensional graphs of urban data collected by a hybrid sensor-enabled electric wheel, in accordance with embodiments of the present inventive concepts.

FIGS. 10A-10C are illustrations of a hybrid sensor-enabled electric wheel installed on a bicycle, in accordance with embodiments of the present inventive concepts.

#### DETAILED DESCRIPTION OF EMBODIMENTS

The terminology used herein is for the purpose of describing particular embodiments and is not intended to be limiting of the inventive concepts. As used herein, the singular forms "a," "an" and "the" are intended to include the plural

forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises,” “comprising,” “includes” and/or “including,” when used herein, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

It will be understood that, although the terms first, second, third etc. may be used herein to describe various limitations, elements, components, regions, layers and/or sections, these limitations, elements, components, regions, layers and/or sections should not be limited by these terms. These terms are only used to distinguish one limitation, element, component, region, layer or section from another limitation, element, component, region, layer or section. Thus, a first limitation, element, component, region, layer or section discussed below could be termed a second limitation, element, component, region, layer or section without departing from the teachings of the present application.

It will be further understood that when an element is referred to as being “on” or “connected” or “coupled” to another element, it can be directly on or above, or connected or coupled to, the other element or intervening elements can be present. In contrast, when an element is referred to as being “directly on” or “directly connected” or “directly coupled” to another element, there are no intervening elements present. Other words used to describe the relationship between elements should be interpreted in a like fashion (e.g., “between” versus “directly between,” “adjacent” versus “directly adjacent,” etc.). When an element is referred to herein as being “over” another element, it can be over or under the other element, and either directly coupled to the other element, or intervening elements may be present, or the elements may be spaced apart by a void or gap.

FIG. 1A is an exploded diagram of a hybrid sensor-enabled electric wheel, and FIG. 1B is a perspective view of a hybrid sensor-enabled electric wheel. The hybrid sensor-enabled electric wheel **100** can comprise a tire **101**, a wheel rim **102**, a plurality of spokes **103**, and a wheel hub **104**.

The wheel rim **102** is connected to the wheel hub **104** via the plurality of spokes **103**. In this exemplary embodiment, first and second ends of each of the plurality of spokes **103** are connected to the wheel rim **102**, and curved portions **103a** of each of the plurality of spokes **103** interface with curved spoke pockets **105** of the wheel hub **104**. In this manner, the curved portions **103a** of the plurality of spokes **103** interface with external side surfaces of the wheel hub **104**, thus connecting the wheel rim **102** to the wheel hub **104**.

In one embodiment, the motorized hub unit is connected to the wheel rim via a plurality of wheel spokes, and the wheel spokes can be under one of tension and compression. In another embodiment, the motorized hub unit is connected to the wheel rim via a mesh material. In another embodiment, the motorized hub unit is connected to the wheel rim via a disk.

Although not shown, the wheel rim **102** and wheel hub **104** can alternately be connected according to conventional wheel spoking paradigms. For example, first ends of each of a plurality of spokes can be connected to the wheel rim **102**, and second ends of each of the plurality of spokes can be connected to the wheel hub **104**. Such conventional spoking paradigms are well known in the art, and thus their further detailed description will be omitted.

Referring to FIGS. 1A and 1B, the wheel hub **104** can include a modular systems package **110**, a rotor **120**, a stator

**130**, a mechanical drive unit **190** that is coupled to and drives an inner wheel hub gear system **140**, a torque sensing system **150**, a motor casing **160**, an optional removable battery cover **170**, an optional coaster brake **180** and a torque arm **186**. With the exception of the torque arm **186** and sprocket portions, all mechanical and electrical components of the electric wheel **100** are packaged within the wheel hub **104**. The modularity and electromechanical packaging of the hybrid sensor-enabled electric wheel **100** provides a system that can be easily retrofitted into various types of two-wheeled bicycles and wheeled vehicles.

Referring to FIG. 3, the wheel hub **104** can comprise an aluminum hub, and can include a rotating unit **104r** and a static unit **104s**. The wheel hub **104** can comprise various other materials, such as plastic materials, metal materials and graphite materials in addition to or instead of aluminum. The spokes **103** can be connected to the external side surfaces of the rotating unit **104r**, which houses the rotor **120** and inner wheel hub gear system **140**. The static unit **104s** houses the modular systems package **110**, the stator **130** and the torque sensing system **150**.

Referring back to FIGS. 1A and 1B, the modular system package **110** can comprise a control unit **3000** including an optional telecommunications and global positioning system unit **111**, a motor controller **112** and an optional environmental sensor systems unit **115**. The modular system package **110** can further comprise one or more batteries or energy storing devices **113**, **113a-d**. A removable battery cover **170** of the wheel hub **104** can provide access to the one or more batteries or energy storing devices **113**, **113a-d** of the modular system package **110**. The modular system package **110** is described in further detail below with regard to FIG. 2C.

Together, the rotor **120** and the stator **130** form the motor **135** of the hybrid sensor-enabled electric wheel **100**. The motor **135** can comprise, for example, a frameless direct drive rotary motor such as the F and FH Series Frameless DDR Servo Motors by Kollmorgen of Radford, Va., USA, which is now part of the Danaher Corporation of Washington D.C., USA. In one embodiment, the motor **135** comprises a Kollmorgen F4309A-111 frameless motor. However, other types of motors can be integrated within the hybrid sensor-enabled electric wheel **100** without departing from the spirit and scope of the present inventive concepts described herein.

The inner wheel hub gear system **140** can comprise automatic or manual shifting gears. With automatic shifting gears, the gear shifting is controlled based on a combination of a torque applied by the cyclist and motor **135**, and velocity of the wheel **100**. In one embodiment, the inner wheel hub gear system comprises a Shimano Nexus 3-speed gear system with coaster brake by Shimano of Osaka, Japan. However, other types of inner wheel hub gear systems can be integrated within the hybrid sensor-enabled electric wheel **100** without departing from the spirit and scope of the present inventive concepts described herein.

The wheel hub **104** can further comprise a torque sensing system **150**, a motor casing **160** and a coaster brake **180**. In some embodiments, mechanical braking occurs through the coaster brake **180** and/or the inner wheel hub gear **140**, and is controlled by the amount of negative torque applied to pedals by a cyclist. For example, a cyclist can active mechanical braking by back-pedaling.

In addition to mechanical braking, regenerative braking is available in some embodiments. Regenerative braking can also be activated in response to the back-pedaling of a cyclist. For example, a torque and velocity applied by a

back-pedaling cyclist can be measured via the torque sensing system **150**. In response to the measured torque and/or velocity, the control unit **3000** of the modular system package **110** can activate regenerative braking.

For example, when a cyclist back-pedals, regenerative braking controlled via the control unit **3000** of the modular system package **110** is activated. That is, the electric motor **135** of the wheel **100**, acting as a generator, generates a supplemental negative torque, and the energy generated in response to the supplemental negative torque is transferred and stored in the one or more batteries or energy storing devices **113** of the wheel **100**.

In some embodiments, mechanical braking occurring through the coaster brake **180** and/or the inner wheel hub gear **140** is activated when regenerative braking can not provide a sufficient amount of negative torque. That is, as a cyclist applies a greater negative torque (i.e., back-pedals harder), mechanical braking can be activated.

For example, as a cyclist back-pedals harder (i.e., applies a greater negative torque) the mechanical braking is activated in addition to the regenerative braking. However, in some embodiments, regenerative braking is deactivated in response to the activation of mechanical braking.

FIGS. 2A-2C are plan and section views of a hybrid sensor-enabled electric wheel. The hybrid sensor-enabled electric wheel **100** can be manufactured in various sizes such that the wheel **100** can be retrofitted into various types of two-wheeled bicycles and other wheeled vehicles. FIG. 2A shows a first set of spokes **98** and a second set of spokes **96** whose ends are alternately connected around an inner circumference **105** of the wheel rim **103** and spoke pockets **106**.

The hybrid sensor-enabled electric wheel **100** has an overall length (i.e., diameter) **L1** along a vertical axis **200**, which can range, in some embodiments, between about 200 millimeters and about 724 millimeters. In one embodiment, the length **L1** is about 642 millimeters $\pm$ 2 millimeters. The hybrid sensor-enabled electric wheel **100** has an overall width **W1** along a horizontal axis **201**, which can range, in some embodiments, between about 90 millimeters and about 115 millimeters. In one embodiment, the width **W1** is about 115 millimeters $\pm$ 2 millimeters.

The wheel hub **104** of the hybrid sensor-enabled electric wheel **100** has an overall length (i.e., diameter) **L2** along the vertical axis **200**, which can range, in some embodiments, between about 200 millimeters and about 500 millimeters. In one embodiment, the length **L2** is about 314.325 millimeters $\pm$ 2 millimeters.

Referring to FIG. 2C, the wheel hub **104** can comprise the modular systems package **110**, which can be packaged within the wheel hub **104** of the hybrid sensor-enabled electric wheel **100**. As such, the modular systems package **110** can be protected from external environmental conditions by the outer casing of the wheel hub **104**. In some embodiments, a conformal coating material is applied to the modular systems package **110** and/or its components to protect against environmental conditions, such as moisture, dust, dirt and debris.

As described above, the modularity and electromechanical packaging of components and systems within the wheel hub **104** of the hybrid sensor-enabled electric wheel **100** allows for the wheel **100** to be easily retrofitted into various types of two-wheeled bicycles without requiring various types of wiring harnesses, cable ties, and external battery packs secured to a frame of a bicycle.

The modular system package **110** can comprise an optional telecommunications and global positioning system

unit **111**, a motor controller **112**, one or more batteries or energy storing devices **113**, **113a-e**, one or more control units **114** and an optional environmental sensors system **115**.

The one or more control units **114** can comprise a micro-processing system that is configured to communicate with and control the motor controller **112** (see for example, unit **811** of FIG. 8). The micro-processing system of the one or more control units **114** can further be configured to communicate with and control the optional telecommunications and global positioning system unit **111**.

The telecommunications and global positioning system unit **111** can comprise a global positioning system (GPS) unit or other location positioning technology that can provide location and time data, and a telecommunications system unit that can provide access to mobile/cellular data networks (see for example, unit **815** of FIG. 8). In one embodiment, the telecommunications system unit comprises a general packet radio service (GPRS) unit or other wireless technology that can provide access to 2G and 3G cellular communications systems or other modes of wireless communications. However, the telecommunications system unit can comprise various other types of 2G, 3G and 4G telecommunications systems. In some embodiments, the telecommunications and global positioning system unit **111** is integrated within the one or more control units **114**.

The motor controller **112** can comprise a 3-phase brushless DC motor driver that generates 3 phases of drive current based on the rotor **120** position/orientation (see for example, units **804**, **804a**, **804b** of FIG. 8). The motor controller **112** can determine the rotor position/orientation/velocity using hall effect sensors, rotary position sensors, or by measuring the back EMF in undriven coils. In other embodiments, the motor controller **112** can comprise a motor driver associated with the specific type of motor **135** integrated within the wheel **100**.

The one or more batteries or energy storing devices **113**, **113a-e** can comprise one or more rechargeable batteries, one or more bulk capacitors, or a combination thereof. The one or more batteries **113**, **113a-e** can be configured as a single, removable battery pack.

In one embodiment, the batteries **113** comprise 18 Superior Lithium Polymer Batteries (SLPB 486495) by Kokam Engineering Co., LTD of Gyeonggi-do, Republic of Korea. In this embodiment, each of the 18 Superior Lithium Polymer Batteries (SLPB 486495) has a nominal voltage of 3.7 volts and a capacity of 3 amp-hours; the battery system is configured to have a voltage of 22.2 volts and a capacity of 9 amp-hours, and weighs about 1.062 kilograms. As such, the battery system is configured with 3 parallel-connected sets of 6 series-connected batteries. In some embodiments, the batteries are stationary within the wheel hub **104**.

The environmental sensors system **115** can comprise a gas analyzer capable of measuring at least one of CO, CO<sub>2</sub>, NOx, O<sub>2</sub> and O<sub>3</sub> content and/or particulate sensor for measuring large and small air particulates. The environmental sensors **115** can comprise a temperature and humidity sensor for measuring ambient temperature and relative humidity. The environmental sensors **115** can comprise a noise sensor for measuring environmental noise pollution.

FIG. 3 is a cross-sectional view of the hybrid sensor-enabled electric wheel of FIG. 2A taken along lines A-A'.

As described above, the wheel hub **104** can include a rotating unit **104r** and a static unit **104s**. The spokes **103** can be connected to the external side surfaces of the rotating unit **104r**, which houses the rotor **120** and inner wheel hub gear

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system 140. The static unit 104s houses the modular systems package 110, the stator 130 and the torque sensing system 150.

In this illustrative example, the batteries 113 are positioned concentrically within the wheel hub 104 with respect to the horizontal axis 201. As such, the batteries 113 are positioned within the wheel hub 105 so as to reduce the bulk of the wheel hub casing.

FIG. 4A is a perspective view of a torque sensing system for hybrid sensor-enabled electric wheels. The torque sensing system 150 can comprise an inner sleeve 1501, an outer sleeve 1502 and a proximity sensor 1504. The inner and outer sleeves 1501, 1502 comprise opposing ramps 1503, 1503a-b, which can affect a lateral displacement LD between the inner sleeve 1501 and the outer sleeve 1502.

For example, when a torque is applied to one of the inner and outer sleeves 1501, 1502, the inner sleeve 1501 can rotate R in a clockwise or counterclockwise direction with respect to the outer sleeve 1502. The rotation R of the inner sleeve 1501 causes the ramp 1503a of the inner sleeve 1501 to ride up or down the ramp 1503b of the outer sleeve 1502. Accordingly, the rotation R of the inner sleeve 1501 can affect the lateral displacement LD between the inner sleeve 1501 and the outer sleeve 1502. That is, as the ramp 1503a of the inner sleeve 1501 rides up the ramp 1503b of the outer sleeve 1502, the lateral displacement LD between the inner and outer sleeves 1501, 1502 increases, and as the ramp 1503a of the inner sleeve 1501 rides down the ramp 1503b of the outer sleeve 1502, the lateral displacement LD between the inner and outer sleeves 1501, 1502 decreases.

A proximity sensor 1504 can be provided on the inner or outer sleeve 1501, 1502 so that the lateral displacement LD between the inner and outer sleeve 1501, 1502 can be measured. A proximity sensor 1504 is shown provided on a surface of the outer sleeve 1502.

The inner sleeve 1501 can be provided with a notch 1505 that can interface with a spring/elastomer mechanism 1510 (shown and described below in detail in connection with FIG. 4D). The spring/elastomer mechanism 1510 applies a known force (i.e., by way of a known spring constant) on the inner sleeve 1501 via the notch 1505 of the inner sleeve 1501.

Accordingly, a torque applied to one of the inner and outer sleeves 1501, 1502 can be calculated from a combination of a measured lateral displacement LD and a known force applied to the notch of the inner sleeve 1501.

FIG. 4B is a perspective view of a torque sensing system for hybrid sensor-enabled electric wheels. Elements having the same functions as those described above are indicated by like reference identifiers, and thus their detailed description will not be repeated.

The torque sensing system 150 illustrated in FIG. 4B operates in a similar manner as the torque sensing system 150 illustrated in FIG. 4A; however, the proximity sensor 1504 of the torque sensing system 150 illustrated in FIG. 4A is replaced with a displacement sensor 1506 comprising a spring/elastomer 1506a and pressure sensor 1506b, or other technologies for measuring distance such as resistive, capacitive, or other types of distance measurement technologies.

FIG. 4C is a perspective view of a torque sensing system for hybrid sensor-enabled electric wheels. Elements having the same functions as those described above are indicated by like reference identifiers, and thus their detailed description will not be repeated.

The torque sensing systems 150 described throughout the application can further comprise a velocity sensing system

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including one or more hall effect sensors 1507 and a plurality of magnets 1508. In one embodiment, the magnets 1508 are provided in an alternating configuration on an outer surface of the inner sleeve 1501, and spaced apart by a predetermined distance dl. That is, the magnets 1508 provided on the outer surface of the inner sleeve alternate magnetic poles (e.g., N-S-N-S-N-S). In this manner, a velocity measurement can be calculated based on a time-distance relationship.

FIG. 4D illustrates several views of a spring/elastomer mechanism of a torque sensing system for hybrid sensor-enabled electric wheels. Elements having the same functions as those described above are indicated by like reference identifiers, and thus their detailed description will not be repeated.

A spring/elastomer mechanism 1510 of a torque sensing system 150 can comprise first and second springs/elastomers 1511 and optional pressure sensors 1513. The first and second springs/elastomers 1511 are provided in a cylindrical housing 1514 of the outer sleeve 1502, and are configured to provide a gap region 1512 so that the notch of 1505 of the inner sleeve 1501 can be provided in the gap region 1512. As described above, the spring/elastomer mechanism 1510 can apply a known force (i.e., by way of a known spring constant) on the inner sleeve 1501 via the notch 1505.

Referring to FIGS. 1-4D, the hybrid sensor-enabled and autonomous electric wheel 100 can be fully controlled via bicycle pedals by sensing a torque that is applied by a cyclist. For example, when a cyclist applies a positive torque to the inner wheel hub gear system 140 via bicycle pedals, the hybrid sensor-enabled and autonomous electric wheel 100 supplements the positive torque applied by the cyclist by a predetermined amount. That is, for example, the electric motor 135 of the wheel 100 provides a predetermined amount of positive torque. In another example, when a cyclist applies negative torque (e.g., activates a pedal brake, back-pedals) the hybrid sensor-enabled and autonomous electric wheel 100 supplements the negative torque applied by the cyclist. That is, for example, the electric motor 135 of the wheel 100 generates a supplemental negative torque. In some embodiments, the energy generated by the supplemental negative torque is transferred and/or stored in one or more batteries or energy storing devices 113 of the wheel 100.

In some embodiments, a smartphone, such as the smartphone illustrated in FIG. 10C, can be configured to communicate with the motor controller 112 or the one or more control units 114 of the hybrid sensor-enabled and autonomous electric wheel 100 via Bluetooth, or other wireless protocol. The smartphone can be configured to access, receive and display various types of data collected by sensors of the wheel, and can configure the data collection processes. For example, the smartphone can configure the one or more control units 114 and sensor systems of the wheel 100 to collect various types of environmental and location data.

The smartphone can also be configured to control operational modes of the hybrid sensor-enabled and autonomous electric wheel 100. For example, a cyclist can configure the wheel 100, via the smartphone, to operate in an energy regeneration mode or exercise mode such that an electric motor 135 of the wheel 100 generates and transfers electrical energy to the one or more batteries or energy storing devices 113 of the wheel 100 while the cyclist is pedaling.

Although a smartphone is described above, various other types of wireless electronic devices such as tablet computers, netbooks and laptops or other wireless control units can

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be configured to communicate with the motor controller 112 or the one or more control units 114 or 115 of the hybrid sensor-enabled and autonomous electric wheel 100. In another embodiment, a cable connected lever, such as a hand operated handle bar lever, can be connected to the motor controller 112 so as to control one of a drive torque or braking torque of the motor.

In one embodiment, a torque sensing system also comprises a circular pressure sensor or a plurality of point-like pressure sensors placed between the sprocket and the shaft that runs across the hub, covering the area of contact between the sprocket and the shaft. Pressure measurements sample the linear force applied horizontally, in the direction of movement, which is converted to a measure of torque.

In one embodiment, a torque sensing system also comprises a linear tension sensor placed lengthwise inside the shaft that runs across the hub to measure the bending of the shaft which occurs while torque is applied on the sprocket. Tension measurements sample a fraction of the linear force applied horizontally, in the direction of movement, which is converted to a measure of torque. A capacitive as well as resistive sensor can be used for acquiring the same measurement and placed inside the shaft.

FIG. 5 is a perspective view of a wheel spoke.

As described above with reference to FIG. 1A, the wheel rim 102 is connected to the wheel hub 104 via a plurality of spokes 103. First and second ends 103b, 103c of each of the plurality of spokes 103 are connected to the wheel rim 102, and curved portions 103a of each of the plurality of spokes 103 interface with curved spoke pockets 105 of the wheel hub 104. In this manner, the curved portions 103a of the plurality of spokes 103 interface with external surfaces of the wheel hub 104, thus connecting the wheel rim 102 to the wheel hub 104. The rim can also connect to the hub by a plurality of linear spokes that interface with the surface of the hub either through a hole or by a hook, rather than a standard flange.

Referring to FIG. 5, the spokes 103 have a length L4, which can range, in some embodiments, between about 100 millimeters and about 600 millimeters. In one embodiment, the length L4 is about 341 millimeters±2 millimeters. The spokes 103 have a diameter D1, which can range, in some embodiments, between about 1 millimeters and about 5 millimeters. In one embodiment, the diameter D1 is about 2 millimeters±0.25 millimeters.

In some embodiments, first and second ends 103b, 103c of the spokes 103 can be threaded. The threaded portion of the spokes 103 can have a pitch P1, which can range, in some embodiments, between about 0.25 millimeters and about 0.45 millimeters. In one embodiment, the pitch P1 is about 0.45 millimeters±0.2 millimeters. In addition, the threaded portion of the spokes can have a threads per inch (tpi) count T1, which can range, between about 22 tpi and about 62 tpi. In one embodiment, the tpi count can be about 56 tpi±5 tpi. In some embodiments, the tpi count can be a standard nipple thread count associated with bicycle rims or other wheeled vehicles.

Generally, the spoke count 'n', length L4, diameter D1, pitch P1 and tpi count T1 is determined by the size of the wheel 100 and its application. In one embodiment, the wheel rim 102 is connected to the wheel hub 104 via 18 bent wire spokes 103 (see for example FIG. 7). However, in other embodiments the number of bent wire spokes 103 can range between about 12 and about 20. In some embodiments, the wheel rim 102 comprises a 700c wheel rim, and the 18 bent wire spokes 103 are threaded into 36 nipples on the wheel rim 102. However, the spoking concept described herein

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with reference to at least FIGS. 5, 6A-6C and 7 can be adapted and modified for any size wheel rim 102 by a skilled artisan after a full and complete disclosure of the present application.

FIGS. 6A-6C illustrate a method of manufacturing a wheel spoke. Although FIGS. 6A-6C disclose a manual method of manufacturing bent wire spokes 103, one skilled in the art would readily understand that the bent wire spokes 103 described herein can be manufactured according to automated processes after a full and complete disclosure of the present application.

Referring to FIG. 6A, a spoke 103 is clamped between a cylindrical roller 601 and a clamping device 602. The cylindrical roller 601 can comprise a pipe, such as a PVC or metal pipe, or a solid roller. The clamping device 602 can comprise a screw clamp, industrial clip, or pliers.

Referring to FIG. 6B, the spokes are bent at a mid-point MP to create a curvature corresponding to the outer curvature of the cylindrical roller 601. In one embodiment, the spokes are bent at the mid-point MP with a curvature ranging between about 15 millimeters to about 20 millimeters.

Referring to FIG. 6C, the resulting bent wire spoke can have a final angle  $\Theta$ , which can range, in some embodiments, between about 20 degrees and about 60 degrees. This spoking mechanism removes the need for a flange on the hub, allows a seamless connection between the spoke and the exterior of the hub and provides a faster spoking method when attaching or removing the hub to or from the wheel. In one embodiment, the final angle  $\Theta$  is about 40 degrees±5 degrees.

In addition to the above method of manufacturing wheel spokes, the wheel spokes 103 described herein can be manufactured according to various other methods, such as forming and forging methods, molding methods and injection methods.

FIGS. 7A-7E illustrate wheel spoke configurations. The illustrated wheel spoke configuration comprises a first set of bent wire wheel spokes 103 (e.g., 1a, 2a, 4a, 5a, 6a, 7a, 8a, 9a) and a second set of bent wire wheel spokes 103 (e.g., 1b, 2b, 3, 4b, 5b, 6b, 7b, 8b, 9b) that alternately interface with first and second sides 104a, 104b of wheel hub 104. That is, curved portions 103a of each of the bent wire wheel spokes 103 of the first set (e.g., 1a, 2a, 4a, 5a, 6a, 7a, 8a, 9a) interface with corresponding curved pockets 2000 on the first side 104a of the wheel hub 104, and curved portions 103a of each of the bent wire wheel spokes 103 of the second set (e.g., 1b, 2b, 3, 5b, 8b, 6b, 7b, 8b, 9b) interface with corresponding curved pockets 2000 on the second side 104b of the wheel hub 104. Further, in this illustrated configuration, the bent wire wheel spokes 103 are alternately arranged around the inner circumference of the wheel rim 102 such that bent wire wheel spokes 103 of the first and second sets alternate (e.g., 1a, 1b, 2a, 2b, 3, 4a, 4b, 5a, 8b, 6a, 6b, 7a, 7b, 8a, 8b, 9a, 9b).

Referring to FIGS. 7A and 7B, in some embodiments, the curved portions 103a of the bent spokes 103 can interface with curved spoke pockets 2000 provided on sides of the wheel hub 104. The curved spoke pockets 2000 can be provided as indentations within the outer casing of the wheel hub 104.

Referring to FIG. 7C, in some embodiments, the curved portions 103a of the bent spokes can interface with an enclosed channel provided within the outer casing of the hub wheel 104. As such, wire or rope wheel spokes 103 can be threaded through the enclosed channel 2001.

Referring to FIG. 7D, in some embodiments, the curved portions **103a** of the bent spokes can interface with hooks or protrusions **2002** provided on sides of the wheel hub **104**.

Referring to FIG. 7E, in some embodiments, the curved portions **103a** of the bent spokes can interface with an external clasp **2003** provided on the outer casing of the hub wheel **104**.

Although the illustrated wheel spoke configuration of FIG. 7 comprises 18 bent wire wheel spokes **103**, the spoking concept described herein can be adapted and modified for to include any number 'n' of bent wire wheel spokes by a skilled artisan after a full and complete disclosure of the present application. In addition, the wheel spokes may comprise of other materials, including, but not limited to wire rope, or mesh. Moreover, the wheel spoking configuration described herein can be adapted and modified for any type of vehicle wheel (e.g., automobile, motorcycle, scooter, ext . . . ) by a skilled artisan after a full and complete disclosure of the present application.

FIG. 8 is a block diagram of a control and sensor system and a motor controller for a hybrid sensor-enabled electric wheel.

The control unit **114** can comprise a micro-processing system **811**, an optional Bluetooth communications unit **810**, an accelerometer **813**, a telecommunications and global positioning system unit **815** and a plurality of environmental sensors **816**, **817**, **821**, **822**.

The micro-processing system **811** can be configured to communicate with and control the motor controller **112**, and can comprise a debug serial port **814** and a PGM port **812**. In this exemplary embodiment, the input/output lines of the micro-processing system **811** are connected to the output/input lines of the micro-processing system **801** of the motor controller **112**, respectively. In some embodiments, the connection between the micro-processing system **811** of the control unit **114** and the micro-processing system **801** of the motor controller **112** can be isolated.

The environmental sensor **816** can comprise a gas analyzer capable of measuring at least one of CO, NOx, O<sub>2</sub> and O<sub>3</sub> content. The environmental sensor **817** can comprise a particulate sensor for measuring large and small air particulates. The environmental sensor **821** can comprise a temperature and humidity sensor for measuring ambient temperature and relative humidity. The environmental sensor **822** can comprise a noise sensor for measuring environmental noise pollution.

The telecommunications and global positioning system unit **815** can comprise a global positioning system (GPS) unit that can provide location and time data, and a telecommunications system unit that can provide access to mobile/cellular data networks. In one embodiment, the telecommunications system unit comprises a general packet radio service (GPRS) unit that can provide access to 2G and 3G cellular communications systems. However, the telecommunications system unit can comprise various other types of 2G, 3G and 4G telecommunications systems.

The motor controller **112** can comprise a micro-processing system **801**, an optional Bluetooth communications unit **810**, a power supply **805**, a 3-phase brushless DC motor driver **804** and a piezo alarm buzzer **821**.

The 3-phase brushless DC motor driver **804** generates 3 phases of drive current **804a** based on the rotor **120** position/orientation in response to drive signals output by the micro-processing system **801**. The motor controller **112** can determine the rotor position/orientation using hall effect sensors **804b**, rotary position sensors, or by measuring the back EMF in undriven coils. In other embodiments, the motor

controller **112** can comprise a motor driver associated with the specific type of motor **135** integrated within the wheel **100**.

In some embodiments, the hybrid sensor-enabled electric wheel systems **112**, **114** can be configured and/or controlled via a wireless control system **5000**. The wireless control system can comprise a micro-processing system **823**, a low battery light **824**, an display **825**, a mode selector button **826**, a Bluetooth communications unit **810** and a Bluetooth connection light **827**.

The wireless control system **5000** can be configured to wirelessly communicate with the systems **112**, **114** via the Bluetooth communications unit **810** or other wireless communication protocol device. The wireless control system **5000** is provided with a Bluetooth connection light **827**, which can indicate a connection status with the systems **112**, **114** of the wheel **100**.

The wireless control system **5000** can be configured to access, receive and display various types of data collected by sensors of the wheel, and can configure the data collection processes. For example, the wireless control system **5000** can configure the control unit **114** and sensor systems of the wheel **100** to collect various types of environmental and location data.

The wireless control system **5000** can also be configured to control operational modes of the hybrid sensor-enabled and autonomous electric wheel **100**. For example, a cyclist can configure the wheel **100**, via the wireless control system **5000**, to operate in an energy regeneration mode or exercise mode such that an electric motor **135** of the wheel **100** generates and transfers electrical energy to the one or more batteries or energy storing devices **113** of the wheel **100** while the cyclist is pedaling.

FIGS. 9A and 9B are 3-dimensional graphs of urban data collected by a hybrid sensor-enabled electric wheel.

As a cyclist rides, a global positioning system (GPS) unit and one or more sensing units **115** of the hybrid sensor-enabled and autonomous electric wheel **100** capture information about a cyclist's personal riding habits including location and time data, and caloric loss data, as well as environmental information including carbon monoxide data, NOx data, noise data, ambient temperature data and relative humidity data.

In some embodiments, the cyclist can access this data through a smartphone, or via the internet, which can help a cyclist plan healthier bike routes, achieve exercise goals, or to meet up with friends on the go. The cyclist can also share collected data with friends, through online social networks, or with researchers through online data collection warehouses.

Data collected from the plurality of sensors in **115** can be analyzed and the results can be made available to the cyclist via an Internet application. The collected data can also be made available to a cyclist in real time via a smartphone wirelessly connected to the wheel **100**.

Cyclists who wish to can share the data they are collecting with a city bike system. The city bike system and applications can provide cities with the ability to query the aggregated data that is collected by cyclists, which can be used in planning and design decision-making processes.

The data collected by the wheel can be used in combination with caloric loss data and torque information to provide cyclists with statistical and real-time information about their physical performance while riding.

Information about cyclist routes can be analyzed to produce information about the cyclists' environmental impact

including: a comparison between travel with different modes of transportation (car, motorbike, bike, walk, etc.).

A Green Mileage Scheme can provide an incentive for cyclists to use their bike more. It can allow cyclists to collect the number of 'green miles' they cycle, to compete with friends or to exchange miles for goods and services in the city.

A Real-Time Delivery Service community can be created using the rich data collection features of the wheel **100**. The service can exploit the untapped freight capacity of cyclists for delivering goods within a city. Members of the community can contact other members via text message or an alert on via a smartphone and offer incentives for delivering goods to their final destination.

Referring to FIG. **9A**, the data collected from sensors on the bike can generate detailed analyses of temporal environmental phenomena in cities. This can include CO levels (**901**); NOx levels (**902**); noise levels (**903**); and traffic patterns and congestion (**904**). This information can be overlaid on existing street patterns, land use maps (**905**) and open space maps (**906**) to create a tool cities and individuals can use, for example, to monitor environmental conditions; for future environmental and traffic policy decisions; real time traffic analysis; the study of phenomena like urban heat islands, noise and environmental pollution; and when planning the least polluted routes through cities. Referring to FIG. **9B**, detailed 3D maps of environmental pollutants in cities can be generated through the data collected on the bikes. These maps that can be accessed through mobile devices or a standard webpage and can provide an overview of environmental conditions in real time, as well as historical data detailing past conditions or predictions of future conditions. In this way, they can be seen as a tool for planning new routes in cities as well as analyzing future and past conditions.

FIGS. **10A-10B** are drawings and an image of a hybrid sensor-enabled electric wheel installed on a bicycle. After the wheel **100** is secured to the frame **1000** of the bicycle using a mechanical coupling mechanism **1005**, which may be a shaft, the torque arm **186** is attached to the frame **1000** and a bicycle chain **1002** is installed. The bicycle chain **1002** is connected to a pedal sprocket **1001** of the mechanical drive unit **190**, that drives the inner wheel hub gear system **140** of the wheel **100**. The mechanical drive unit may include a sprocket or gears. In this manner, a cyclist can apply positive or negative torque to the inner wheel hub gear system **140** via the bicycle pedals **1003**, pedal sprocket **1001** and bike chain **1002**.

Referring to FIG. **10C**, a smartphone is shown secured to a handlebar of a two-wheeled bicycle. The smartphone **1050** (optional) can be secured to the handlebar **1051** of the bicycle via a handlebar control unit **1052**.

The smartphone **1050** can be configured to wirelessly communicate with the hybrid sensor-enabled and autonomous electric wheel **100** via Bluetooth, or other wireless protocol, and can configure operating modes of the wheel **100** and/or access and receive various types of data collected by sensors of the wheel **100**.

In some embodiments, a cyclist can configure the wheel **100** to operate in at least one of the following operational modes:

**OFF MODE:** The motor **135** of the wheel **100** is deactivated (i.e., off), and the bike can be pedaled and ridden normally. In this mode, regenerative braking, mechanical braking and gear changes are enabled.

**PEDAL ASSIST 1/2/3:** The motor **135** of the wheel **100** is activated (i.e., enabled) and supplies a predetermined

magnitude of torque. In some embodiments, the motor **135** multiples the cyclist torque by  $\times 1$ ,  $\times 1.5$  or  $\times 2$ .

**EXERCISE 1/2/3:** The motor **135** of the wheel **100** is configured as a generator, and the one or more batteries or charge storage devices **113** are charged by the cyclist. In one embodiment, there are three different modes for exercise in this setting: easy, medium and hard.

**SMOOTH ZERO EMISSION:** In Zero Emission mode the bike uses the energy that is collected while braking (regenerative braking) to make the ride smoother for the cyclist. For example, energy collected while going downhill is released when going uphill. The amount of energy released is calculated so that the total balance is zero.

Accordingly, a smoother ride can be achieved without the need of energy supplementation from the grid to charge the batteries.

The hybrid sensor-enabled and autonomous electric wheel **100** can comprise a battery management system, which the smartphone can be configured to wirelessly communicate with via Bluetooth, or other wireless protocol. The battery management system can communicate to the smartphone **1050** the battery charge level of the one or more batteries or charge storage devices **113** of the wheel **100**.

The smartphone **1050** can further activate or deactivate an integrated locking and alarm system of the wheel **100**. The integrated locking and alarm system can be activated wirelessly via the smartphone **1050** or can be armed with a key switch on the hub.

When locked, the control unit **114** of the wheel **100** can configure the motor drive **804** of the motor controller **112** to enter a high-impedance state thereby preventing axial rotation AR of the wheel **100**. In addition, the alarm system can be configured to detect undesired movement of the wheel **100** via the accelerometer **813** of the control unit **114**. When undesired movement is detected an audible alarm can sound. Further, the control unit **114** can be configured to report GPS coordinates and a time stamp when the alarm is triggered. In some embodiments, the control unit **114** can report the GPS coordinates and time stamp by sending an electronic message, such as an email message or txt message, via the control units **114** telecommunications system unit.

While the present inventive concepts have been particularly shown and described above with reference to exemplary embodiments thereof, it will be understood by those of ordinary skill in the art, that various changes in form and detail can be made without departing from the spirit and scope of the present inventive concepts described above and defined by the following claims.

What is claimed is:

1. A wheel comprising:

- a wheel rim;
- a wheel hub having a first side and a second side, each of said first sides and second sides having an external side surface with spoke pockets formed therein, the spoke pockets having a shape corresponding to an attachment section of a respective spoke for retaining and securing the attachment section of a respective spoke; and
- a first set and a second set of a plurality of wheel spokes providing a connection of the wheel rim to the wheel hub, each of the plurality of wheel spokes has a first end, a second end, and an attachment section therebetween, corresponding to one of the spoke pockets, the first end and the second end extending at an angle with respect to each other and attaching to the wheel rim,



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wherein each attachment section retained and secured by the respective spoke pocket allows for said connection of the wheel rim to the wheel hub.

2. The wheel of claim 1, wherein each attachment section of the first set and the second set of the plurality of wheel spokes has a shape that is one of: a curved shape or a bent shape.

3. The wheel of claim 1, wherein the spoke pocket of either the first external side surface or the second external side surface has a shape that is one of: a curved shape or a bent shape.

4. The wheel of claim 1, wherein the angle of each attachment section of the first set and the second set of the plurality of wheel spokes ranges between 20 degrees and 60 degrees.

5. The wheel of claim 1, wherein the angle of each attachment section of the first set and the second set of the plurality of wheel spokes is 35 degrees to 45 degrees.

6. The wheel of claim 1, wherein the ends of the first set of the plurality of wheel spokes and the ends of the second set of the plurality of wheel spokes are alternately connected around an inner circumference of the wheel rim.

7. A wheel, comprising:

a wheel rim;

a wheel hub having a first exterior side surface and a second exterior side surface, each of said first and second exterior side surfaces with spoke pockets formed therein, the spoke pockets having a shape corresponding to an attachment section of a respective spoke for retaining and securing the attachment section of a respective spoke; and

a first plurality of wheel spokes providing a connection of the wheel rim to the first exterior side surface of the wheel hub, and a second plurality of wheel spokes providing a connection of the wheel rim to the second exterior side surface of the wheel hub, each of the first plurality of wheel spokes and the second plurality of wheel spokes having a first end, a second end, and an attachment section therebetween corresponding to one of the spoke pockets, the first end and the second end of each of the first plurality of wheel spokes and the second plurality of wheel spokes extending at an angle with respect to each other and attaching to the wheel rim,

wherein each wheel spoke of the first plurality of wheel spokes engages with a respective spoke pocket on the first exterior side surface of the wheel hub such that the attachment section is retained and secured within the respective spoke pocket via an overhang of the spoke pocket, and each wheel spoke of the second plurality of wheel spokes engages with a respective spoke pocket on the second exterior side surface of the wheel hub such that the attachment section is retained and secured within the respective spoke pocket via an overhang of the spoke pocket.

8. The wheel of claim 7, wherein each attachment section forms a shape that is one of a curved shape and a bent shape.

9. The wheel of claim 8, wherein each spoke pocket forms a shape that is one of a curved shape and a bent shape.

10. The wheel of claim 7, wherein each attachment section attaches to the respective spoke pocket such that the attachment section is generally flush with the first exterior side surface or the second exterior side surface of the wheel hub.

11. The wheel of claim 7, wherein the angle ranges between 20 degrees and 60 degrees.

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12. The wheel of claim 7, wherein the angle of each of the first plurality and each of the second plurality of wheel spokes is 35 degrees to 45 degrees.

13. The wheel of claim 7, wherein the first exterior side surface and the second exterior side surface of the wheel hub are convex.

14. A wheel, comprising:

a wheel rim;

a wheel hub having a first exterior side and a second exterior side, each of said first exterior sides and second exterior sides having a surface with spoke pockets formed therein, the spoke pockets having a shape corresponding to an attachment section of a respective spoke for retaining and securing the attachment section of a respective spoke, and

a plurality of wheel spokes providing a connection of the wheel rim to the wheel hub, each of the plurality of wheel spokes has a first end that interfaces with a respective spoke pocket of the wheel hub and a second end that interfaces with the wheel rim.

15. The wheel of claim 14, wherein the first exterior side surface and the second exterior side surface of the wheel hub are convex.

16. The wheel of claim 15, wherein each of the plurality of wheel spokes are threaded on the first end and the second end.

17. The wheel hub of claim 14, wherein both the first exterior side surface and the second exterior side surface of the wheel hub are convex.

18. The wheel of claim 14, wherein each wheel spoke is retained under tension.

19. A wheel comprising:

a central hub having a first external side and a second external side, each of said first external sides and second external sides having a surface with spoke pockets formed therein, the spoke pockets having a shape corresponding to an attachment section of a respective spoke for retaining and securing the attachment section of a respective spoke;

a rim; and

a plurality of spokes providing a connection of the central hub to the rim, each spoke of the plurality of spokes comprising:

at least one threaded portion inserted into the rim; and an attachment portion wherein each attachment portion is retained and secured by the respective spoke pocket allowing for said connection of the wheel rim to the central hub.

20. The wheel of claim 1, wherein each attachment section attaches to a respective spoke pocket such that the attachment section is generally flush with the exterior of the respective side surface of the wheel hub.

21. The wheel of claim 1, wherein the first side surface and the second side surface of the wheel hub are convex.

22. The wheel of claim 7, wherein the ends of each of the first plurality of wheel spokes and the ends of each of the second plurality of wheel spokes are alternately connected around an inner circumference of the wheel rim.

23. The wheel of claim 1, wherein each spoke pocket comprises an enclosed channel, a protrusion or a clasp.

24. The wheel of claim 7, wherein each spoke pocket comprises an enclosed channel, a protrusion or a clasp.

25. The wheel of claim 19, wherein each spoke pocket comprises an enclosed channel, a protrusion or a clasp.