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### Steering apparatus and method of controlling the same

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#### Abstract

A steering apparatus includes a steering wheel provided in a vehicle, a feedback motor including a rotation shaft connected to the steering wheel, an angle sensor configured to output an angle signal corresponding to rotation displacement of the steering wheel, a rack bar connected to a rotation shaft of the wheel provided in the vehicle, a steering motor including a rotation shaft connected to the rack bar, a position sensor configured to output a position signal corresponding to linear displacement of the rack bar assembly, and a processor configured to control the steering motor to linearly move the rack bar based on the angle signal, identify a rack force applied to the rack bar based on the position signal, and control the feedback motor to apply a feedback torque corresponding to the rack force applied to the rack bar to the steering wheel.

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## Background/Summary

### CROSS-REFERENCE TO RELATED APPLICATION

(1) This application claims the benefit of Korean Patent Application No. 10-2023-0037569, filed on Mar. 22, 2023 in the Korean Intellectual Property Office, the disclosure of which is incorporated herein by reference.

### TECHNICAL FIELD

(2) Embodiments of the present disclosure relate to a steering apparatus driven by a motor and a method of controlling the same.

### BACKGROUND

(3) Steering apparatuses detect a steering torque generated by the rotation of a steering wheel and control a motor to supply an auxiliary steering torque proportional to the detected steering torque so that steering control of a vehicle may be performed.

(4) Conventionally, steering apparatuses are formed so that a steering torque generated by the rotation of a steering wheel is transmitted to a rack bar via a rack-pinion mechanical unit, and an auxiliary steering torque generated by a motor is transmitted to the rack bar according to the steering torque generated by the rotation of the steering wheel. That is, the steering torque generated by the steering wheel and the auxiliary steering power generated by the motor are combined to axially move the rack bar.

(5) However, recently, steering-by-wire (SBW) type steering apparatuses have been developed for allowing a rack bar to axially move using only a torque of a motor without a mechanical connection between a steering wheel and the rack bar.

(6) In such steering apparatuses, frictional forces between various members of a mechanical unit constituting the apparatus can decrease or increase as a traveling distance of a vehicle increases. For example, the frictional forces between various members of the mechanical unit may be reduced due to a phenomenon in which a rack-and-pinion mechanical unit, a reducer, etc. are worn or loosened. In addition, rust may occur on the rack-and-pinion mechanical unit, the reducer, etc., thereby increasing the frictional forces between various members of the mechanical unit.

(7) The increase or decrease in the frictional forces between the internal members of the electric power steering apparatus may cause a driver to feel a sense of steering different from a sense of steering at the time of the initial use of the steering apparatus.

#### SUMMARY

(8) Therefore, it is an aspect of the present disclosure to provide a steering apparatus capable of detecting changes in frictional forces between internal members, and a method of controlling the same.

(9) Additional aspects of the disclosure will be set forth in part in the description which follows and, in part, will be obvious from the description, or may be learned by practice of the disclosure.

(10) In accordance with one aspect of the present disclosure, a steering apparatus includes a feedback motor including a rotation shaft connected to a steering wheel provided in a vehicle, an angle sensor configured to output an angle signal corresponding to a rotation displacement of the steering wheel, a steering motor including a rotation shaft connected to a rack bar provided in the vehicle, a position sensor configured to output a position signal corresponding to a linear displacement of the rack bar, and at least one processor control the steering motor to linearly move the rack bar based on predetermined target positions, identify a rack force applied to the rack bar based on the position signal of the position sensor, control the feedback motor based on a predetermined feedback torque, identify a feedback torque applied to the steering wheel based on the angle signal of the angle sensor, and provide an output device of the vehicle with an electrical signal indicating whether an increase in a frictional force of at least one of the rack bar or the steering wheel occurs based on the identified rack force and the identified feedback torque.

(11) The at least one processor may identify the increase in the frictional force of the rack bar based on the identified rack force being greater than a predetermined reference rack force, and identify the increase in the frictional force of the steering wheel based on the identified feedback torque being greater than a predetermined reference feedback torque.

(12) The at least one processor may provide the electrical signal to the output device to output a message warning of a low temperature causing the increases in the frictional forces of the rack bar and the steering wheel based on the identified rack force being greater than a predetermined reference rack force and the identified feedback torque being greater than a predetermined reference feedback torque.

(13) The at least one processor may provide the electrical signal to the output device to output a message warning of introduction of foreign substances into the rack bar based on the identified

rack force being greater than a predetermined reference rack force and the identified feedback torque being not greater than a predetermined reference feedback torque.

(14) The at least one processor may provide the electrical signal to the output device to output a message warning of a mechanical defect of the steering wheel based on the identified rack force being not greater than a predetermined reference rack force and the identified feedback torque being greater than a predetermined reference feedback torque.

(15) The at least one processor may identify a normal operation of the steering apparatus based on the identified rack force being not greater than a predetermined reference rack force and the identified feedback torque being not greater than a predetermined reference feedback torque.

(16) The predetermined target positions may include target positions whose displacements from an origin change in a form of a triangular or trapezoidal. The predetermined feedback torque may include a feedback torque whose magnitude changes in a form of a triangular or trapezoidal.

(17) The at least one processor may include a first processor electrically connected to the feedback motor and the angle sensor, and a second processor electrically connected to the steering motor and the position sensor. The first processor may communicate with the second processor.

(18) In accordance with another aspect of the present disclosure, a method of controlling a steering apparatus including a steering wheel provided in a vehicle and a rack bar connected to a rotation shaft of the wheel provided in the vehicle includes controlling a linear movement of the rack bar based on predetermined target positions, identifying a rack force applied to the rack bar based on a position signal of a position sensor, the position sensor configured to output the position signal corresponding to a linear displacement of the rack bar, controlling rotation of the steering wheel based on a predetermined feedback torque, identifying a feedback torque applied to the steering wheel based on an angle signal of an angle sensor, the angle sensor configured to output the angle signal corresponding to a rotation displacement of the steering wheel, and providing an output device of the vehicle with an electrical signal indicating whether an increase in a frictional force of at least one of the rack bar or the steering wheel occurs based on the identified rack force and the identified feedback torque.

(19) The providing of the electrical signal corresponding to the increase in the frictional force of the at least one of the rack bar or the steering wheel may include identifying the increase in the frictional force of the rack bar based on the identified rack force being greater than a predetermined reference rack force, and identifying the increase in the frictional force of the steering wheel based on the identified feedback torque being greater than a predetermined reference feedback torque.

(20) The method may further include providing the electrical signal to the output device to output a message warning of a low temperature causing the increases in the frictional forces of the rack bar and the steering wheel based on the identified rack force being greater than a predetermined reference rack force and the identified feedback torque being greater than a predetermined reference feedback torque.

(21) The method may further include providing the electrical signal to the output device to output a message warning of introduction of foreign substances into the rack bar based on the identified rack force being greater than a predetermined reference rack force and the identified feedback torque being not greater than a predetermined reference feedback torque.

(22) The method may further include providing the electrical signal to the output device to output a message warning of a mechanical defect of the steering wheel based on the identified rack force being not greater than a predetermined reference rack force and the identified feedback torque being greater than a predetermined reference feedback torque.

(23) The method may further include identifying that a normal operation of the steering apparatus based on the identified rack force being not greater than a predetermined reference rack force and the identified feedback torque being not greater than a predetermined reference feedback torque.

(24) In accordance with still another aspect of the present disclosure, a steering apparatus includes a steering wheel actuator, and a steering rack actuator. The steering wheel actuator includes a

feedback motor including a rotation shaft connected to a steering wheel provided in a vehicle, an angle sensor configured to output an angle signal corresponding to a rotation displacement of the steering wheel, and a first processor configured to transmit a target position corresponding to the angle signal to the steering rack actuator and control the feedback motor to apply a feedback torque corresponding to a rack force of the steering wheel actuator to the steering wheel. The steering rack actuator includes a steering motor including a rotation shaft connected to a rack bar provided in the vehicle, a position sensor configured to output a position signal corresponding to a linear displacement of the rack bar assembly, and a second processor configured to control the steering motor to linearly move the rack bar based on the target position and identify a rack force applied to the rack bar based on the position signal. The first processor controls the feedback motor based on a predetermined feedback torque and provides an electrical signal indicating whether an increase in a frictional force of the steering wheel occurs to an output device of the vehicle based on a feedback torque value identified based on the angle signal. The second processor controls the steering motor based on a predetermined target position and provides an electrical signal indicating whether an increase in a frictional force of the rack bar occurs to the output device of the vehicle based on a rack force value identified based on the position signal.

(25) A non-transitory computer readable medium storing a computer program, when executed by a processor, to cause the processor to: control a steering motor to linearly move a rack bar based on predetermined target positions; determine a rack force applied to the rack bar based on a position signal, indicating a linear displacement of the rack bar, received from a position sensor; control a feedback motor to rotate a rotation shaft connected to a steering wheel based on a predetermined feedback torque; determine a feedback torque applied to the steering wheel based on an angle signal, indicating a rotation displacement of the steering wheel, received from an angle sensor; and control an output device to output information indicating whether an increase in a frictional force of at least one of the rack bar or the steering wheel occurs based on the determined rack force and the determined feedback torque.

(26) The computer program, when executed by the processor, further causes the processor to: determine the increase in the frictional force of the rack bar based on the determined rack force being greater than a predetermined reference rack force; and determine the increase in the frictional force of the steering wheel based on the determined feedback torque being greater than a predetermined reference feedback torque.

(27) The computer program, when executed by the processor, further causes the processor to control the output device to output a message warning of a low temperature causing the increases in the frictional forces of the rack bar and the steering wheel based on the determined rack force being greater than a predetermined reference rack force and the determined feedback torque being greater than a predetermined reference feedback torque.

(28) The computer program, when executed by the processor, further causes the processor to control the output device to output a message warning of introduction of foreign substances into the rack bar based on the determined rack force being greater than a predetermined reference rack force and the determined feedback torque being not greater than a predetermined reference feedback torque.

(29) The computer program, when executed by the processor, further causes the processor to control the output device to output a message warning of a mechanical defect of the steering wheel based on the determined rack force being not greater than a predetermined reference rack force and the determined feedback torque being greater than a predetermined reference feedback torque.

(30) The computer program, when executed by the processor, further causes the processor to control the output device to output a message indicating a normal state of the steering wheel and the rack bar based on the determined rack force being not greater than a predetermined reference rack force and the determined feedback torque being not greater than a predetermined reference feedback torque.

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## Description

### BRIEF DESCRIPTION OF THE DRAWINGS

- (1) These and/or other aspects of the disclosure will become apparent and more readily appreciated from the following description of the embodiments, taken in conjunction with the accompanying drawings of which:
- (2) FIG. 1 is a view illustrating one example of a steering apparatus according to one embodiment;
- (3) FIG. 2 is a view illustrating one example of a control configuration of the steering apparatus according to one embodiment;
- (4) FIG. 3 is a view illustrating one example of a test signal for identifying an increase in a frictional force by the steering apparatus according to one embodiment;
- (5) FIG. 4 is a view illustrating one example of displacement of a rack bar assembly responding to the test signal illustrated in FIG. 3;
- (6) FIG. 5 is a view illustrating another example of the test signal for identifying the increase in the frictional force by the steering apparatus according to one embodiment;
- (7) FIG. 6 is a view illustrating one example of a steering apparatus according to one embodiment;
- (8) FIG. 7 is a view illustrating one example of a control configuration of the steering apparatus according to one embodiment; and
- (9) FIGS. 8 and 9 are views illustrating a method in which the steering apparatus identifies an increase in a frictional force and the cause of the increase in the frictional force.

### DETAILED DESCRIPTION

- (10) The same reference numbers indicate the same components throughout the specification. The present specification does not describe all elements of embodiments, and general contents or overlapping contents between the embodiments in the technical field to which the disclosure pertains will be omitted. Terms “unit, module, member, and block” used in the specification may be implemented as software or hardware, and according to the embodiments, a plurality of “units, modules, members, and blocks” may be implemented as one component, or one “unit, module, member, and block” may also include a plurality of components.
- (11) Throughout the specification, when a certain portion is described as being “connected” to another, this includes both a case in which the certain portion is directly connected to another and a case in which the certain portion is indirectly connected to another, and the indirect connection includes connection through a wireless communication network.
- (12) In addition, when a certain portion is described as “including” a certain component, this means further including other components rather than excluding other components unless especially stated otherwise.
- (13) Throughout the specification, when a certain member is described as being positioned “on” another, this includes both a case in which the certain member is in contact with another and a case in which other members are present between the two members.
- (14) Terms such as first and second are used to distinguish one component from another, and the components are not limited by the above-described terms.
- (15) A singular expression includes plural expressions unless the context clearly dictates otherwise.
- (16) In each operation, identification symbols are used for convenience of description, and the identification symbols do not describe the sequence of each operation, and each operation may be performed in a different sequence from the specified sequence unless a specific sequence is clearly described in context.
- (17) Hereinafter, an operation principle and embodiments of the present disclosure will be described with reference to the accompanying drawings.
- (18) FIG. 1 is a view illustrating one example of the steering apparatus according to one embodiment. FIG. 2 is a view illustrating one example of a control configuration of the steering

apparatus according to one embodiment.

(19) A steering apparatus **10** may acquire a driver's steering intention through a steering wheel and change a traveling direction of a vehicle according to the acquired steering intention. For example, the steering apparatus **10** may change a direction of a rotation shaft of the wheel according to the driver's steering intention.

(20) For example, as illustrated in FIGS. **1** and **2**, the steering apparatus **10** may include a steering wheel actuator **100** and a steering rack actuator **200**.

(21) The steering wheel actuator **100** may be only electrically connected to the steering rack actuator **200** without being mechanically or fluidically connected thereto.

(22) The steering wheel actuator **100** may acquire the driver's steering intention through the steering wheel. In addition, the steering wheel actuator **100** may provide the steering wheel with a feedback torque corresponding to a rack force acting on wheels of the vehicle.

(23) As illustrated in FIGS. **1** and **2**, the steering wheel actuator **100** may include a steering wheel assembly **110**, an angle sensor **120**, a torque sensor **130**, a feedback motor **140**, a feedback driver **150**, a first communication interface **180**, and a first processor **190**. The steering wheel assembly **110**, the angle sensor **120**, the torque sensor **130**, the feedback motor **140**, the feedback driver **150**, the first communication interface **180**, and the first processor **190** do not correspond to essential components of the steering wheel actuator **100**, and at least some thereof may be omitted.

(24) The steering wheel assembly **110** may include a steering wheel for acquiring a driver's input related to a traveling direction of a vehicle or a driver's steering intention (hereinafter referred to as "steering input") and a steering column for supporting the steering wheel. The steering wheel assembly **110** may rotate clockwise or counterclockwise according to the driver's steering input.

(25) The angle sensor **120** may detect the rotation of the steering wheel assembly **110** by the driver and measure a rotation angle of the steering wheel assembly **110**. The angle sensor **120** may provide the first processor **190** with an electrical signal (hereinafter referred to as "angle signal") corresponding to the measured rotation angle.

(26) The torque sensor **130** may detect the rotation of the steering wheel assembly **110** and measure a torque applied to the steering wheel assembly **110** by the driver. The torque sensor **130** may provide the first processor **190** with an electrical signal (hereinafter referred to as "torque signal") corresponding to the measured torque.

(27) The feedback motor **140** may be connected to the steering wheel assembly **110** through a reducer and may provide a feedback torque to the steering wheel assembly **110**. The reducer may include, for example, a pulley-belt or a plurality of gears.

(28) The feedback motor **140** may include a rotation shaft connected to the steering wheel assembly **110** through the reducer, a rotor connected to the rotation shaft, and a stator fixed to a housing. For example, the rotor may include permanent magnets of which N poles and S poles are alternately arranged along an outer surface thereof, and the stator may include a plurality of teeth arranged along the outer surface of the rotor and a plurality of coils surrounding each of the plurality of teeth.

(29) The rotor may rotate by magnetic interaction with the stator, and the rotation of the rotor may be provided to the rotation shaft. The feedback motor **140** may receive a driving current controlled by the feedback driver **150**. The plurality of coils included in the stator may form magnetic fields rotating around the rotor by the driving current, and the rotor may rotate by magnetic interaction between a magnetic field of the rotor and a magnetic field of the stator.

(30) The feedback driver **150** may control the driving current supplied to the feedback motor **140** according to a feedback control signal of the first processor **190**. For example, the feedback driver **150** may include a 3-phase inverter (or an H-bridge) including a plurality of switching elements for controlling the driving current supplied to the feedback motor **140** and gate drivers for controlling the switching elements included in the 3-phase inverter (or the H-bridge) according to the feedback control signal of the first processor **190**. The gate driver may provide a driving signal for driving

the 3-phase inverter (or the H-bridge) according to the feedback control signal of the first processor **190** to the switching elements of the 3-phase inverter (or the H-bridge). The 3-phase inverter (or the H-bridge) may convert a direct current (DC) power supplied from a battery of the vehicle into an alternating current (AC) power according to the driving signal of the gate driver and provide the converted AC power to the feedback motor **140**.

(31) The first communication interface **180** may transmit and receive communication signals with the steering rack actuator **200** via a communication network NT. For example, the first communication interface **180** may acquire a transmission signal from the first processor **190** and transmit the transmission signal to the steering rack actuator **200** via the vehicle communication network NT. In addition, the first communication interface **180** may acquire a reception signal from the steering rack actuator **200** via the vehicle communication network NT and provide the reception signal to the first processor **190**.

(32) The first communication interface **180** may include, for example, a controller area network (CAN) transceiver for transmitting and receiving signals using a CAN protocol.

(33) The first processor **190** may provide control signals for controlling the steering wheel actuator **100** according to the driver's steering intention.

(34) The first processor **190** may include a first memory **191** storing programs and data for implementing control of the steering wheel actuator **100**.

(35) The first memory **191** may provide the stored programs and data to the first processor **190** and store temporary data generated during operation of the first processor **190**. The first memory **191** may include, for example, volatile memories such as a static random access memory (SRAM) and a dynamic RAM (DRAM) and non-volatile memories such as a read only memory (ROM), an erasable programmable ROM (EPROM), a flash memory, etc.

(36) The first processor **190** may be electrically connected to the angle sensor **120**, the torque sensor **130**, the first communication interface **180**, the feedback driver **150**, and/or the feedback motor **140**.

(37) The first processor **190** may process an angle signal of the angle sensor **120** and/or a torque signal of the torque sensor **130**. The first processor **190** may identify the driver's steering intention based on a result of processing the angle signal and/or the torque signal. In addition, the first processor **190** may identify a target position of the rack bar included in the steering rack actuator **200** corresponding to the driver's steering intention.

(38) The first processor **190** may provide communication signals corresponding to the target position to the first communication interface **180** to transmit the target position to the steering rack actuator **200** via the communication network NT.

(39) In addition, the first processor **190** may acquire communication signals, which correspond to the rack force received from the steering rack actuator **200** via the communication network NT, from the first communication interface **180**. The first processor **190** may identify the rack force based on a result of processing the received communication signal.

(40) The first processor **190** may identify a feedback torque corresponding to the rack force and provide the feedback control signal to the feedback driver **150** so that the feedback motor **140** generates the feedback torque corresponding to the rack force. The feedback driver **150** may control the driving current supplied to the feedback motor **140** according to the feedback control signal. The feedback motor **140** may provide the feedback torque corresponding to the rack force to the steering wheel assembly **110**.

(41) The steering rack actuator **200** may be only electrically connected to the steering wheel actuator **100** without being mechanically or fluidically connected thereto.

(42) The steering rack actuator **200** may move the rack bar to steer the vehicle according to the driver's steering intention. In addition, the steering rack actuator **200** may identify the rack force applied to the rack bar.

(43) As illustrated in FIGS. **1** and **2**, the steering rack actuator **200** may include a rack bar assembly



**210**, a steering motor **240**, a steering driver **250**, a rack bar position sensor **220**, a second communication interface **280**, and a second processor **290**. The rack bar assembly **210**, the steering motor **240**, the steering driver **250**, the rack bar position sensor **220**, the second communication interface **280**, and the second processor **290** do not correspond to essential components of the steering rack actuator **200**, and at least some thereof may be omitted.

(44) The rack bar assembly **210** may be connected to the rotation shaft of the wheel and may linearly move by driving the steering motor **240**. The rack bar assembly **210** may change a direction of the rotation shaft of the wheel in order to change the traveling direction of the vehicle. For example, the rack bar assembly **210** may linearly move to rotate the rotation shaft of the wheel counterclockwise, and thus the vehicle may turn leftward. In addition, the rack bar assembly **210** may linearly move to rotate the rotational shaft of the wheel clockwise, and thus the vehicle may turn rightward.

(45) The steering motor **240** may be connected to the rack bar assembly **210** through the reducer and may provide a torque for linearly moving the rack bar assembly **210**. The reducer may include, for example, a pulley-belt or a plurality of gears.

(46) The steering motor **240** may provide a rotation force for linearly moving the rack bar assembly **210** leftward or rightward according to a steering control signal of the second processor **290**. The rotation of the steering motor **240** may be converted into a linear motion through, for example, a rack gear and a pinion gear.

(47) The steering motor **240** may include a rotation shaft connected to the rack bar assembly **210** through the reducer, a rotor connected to the rotation shaft, and a stator fixed to a housing. A structure of the steering motor **240** is similar to that of the feedback motor **140**, and a detailed description of the steering motor **240** is replaced with the description of the feedback motor **140**.

(48) The steering driver **250** may control a driving current supplied to the steering motor **240** according to the steering control signal of the second processor **290**. For example, the steering driver **250** may include a 3-phase inverter (or an H-bridge) including a plurality of switching elements for controlling the driving current supplied to the steering motor **240** and gate drivers for controlling the switching elements included in the 3-phase inverter (or the H-bridge) according to the steering control signal of the second processor **290**. The gate driver may provide a driving signal for driving the 3-phase inverter (or the H-bridge) according to the steering control signal of the second processor **290** to the switching elements of the 3-phase inverter (or the H-bridge). The 3-phase inverter (or the H-bridge) may convert a DC power supplied from the battery of the vehicle into an AC power according to the driving signal of the gate driver and provide the converted AC power to the steering motor **240**.

(49) The rack bar position sensor **220** may detect a linear motion of the rack bar assembly **210** and measure displacement of the rack bar assembly **210**. For example, the linear motion of the rack bar assembly **210** may be converted into a rotation motion through a power converter, and the rack bar position sensor **220** may measure displacement of the converted rotation motion. The rack bar position sensor **220** may provide the second processor **290** with an electrical signal (position signal) corresponding to the measured displacement of the rack bar assembly **210**.

(50) The second communication interface **280** may transmit and receive communication signals with the steering wheel actuator **100** via the communication network NT. For example, the second communication interface **280** may acquire a transmission signal from the second processor **290** and transmit the transmission signal to the steering wheel actuator **100** via the vehicle communication network NT. In addition, the second communication interface **280** may acquire a reception signal from the steering wheel actuator **100** via the vehicle communication network NT and provide the reception signal to the second processor **290**.

(51) The second communication interface **280** may include, for example, a CAN transceiver for transmitting and receiving signals using a CAN protocol.

(52) The second processor **290** may provide control signals for controlling the steering rack

actuator **200** according to the driver's steering intention.

(53) The second processor **290** may include a second memory **291** for storing programs and data for implementing control of the steering rack actuator **200**.

(54) The second memory **291** may provide the stored programs and data to the second processor **290** and store temporary data generated during operation of the second processor **290**. The second memory **291** may include, for example, volatile memories such as an SRAM and a DRAM and non-volatile memories such as a ROM, an EPROM, a flash memory, etc.

(55) The second processor **290** may be electrically connected to the second communication interface **280**, the steering driver **250**, the steering motor **240**, and/or the rack bar position sensor **220**.

(56) The second processor **290** may acquire communication signals, which correspond to the target position received from the steering wheel actuator **100** via the communication network NT, from the second communication interface **280**. The second processor **290** may identify the target position of the rack bar assembly **210** based on a result of processing the communication signals.

(57) The second processor **290** may provide the steering control signal to the steering driver **250** to move the rack bar assembly **210** to the target position. The steering driver **250** may control the driving current supplied to the steering motor **240** according to the steering control signal. The steering motor **240** may provide a torque for moving the rack bar assembly **210** to the target position.

(58) The second processor **290** may process a position signal of the rack bar position sensor **220**. The second processor **290** may identify a position, a speed, and/or an acceleration of the rack bar assembly **210** based on a result of processing the position signal.

(59) The second processor **290** may identify a rack force applied to the rack bar assembly **210** from the outside such as tires of wheels based on the position, speed, and/or acceleration of the rack bar assembly **210**.

(60) For example, the second processor **290** may identify a restoring force of the rack bar assembly **210** and acquire the rack force by reflecting the restoring force of the rack bar assembly **210** in an equation of motion.

(61) The second processor **290** may identify an estimated position based on an output of the motor position sensor for measuring rotation displacement of the steering motor **240**, identify a measured position based on an output of the rack bar position sensor **220** for measuring a position of the rack bar assembly, and identify a restoring force based on a product of a difference between the estimated position and the measured position and a modulus of elasticity of the reducer.

(62) The second processor **290** may acquire the rack force by reflecting the restoring force of the rack bar assembly **210** in the equation of motion of the rack bar assembly **210**.

(63) For example, as expressed in Equation 1, a product of a restoring force  $F_{sub.b}$  of the rack bar assembly **210** and a reduction ratio  $R$  of the reducer may be equal to the sum of a rack force  $F_{sub.road}$  of the rack bar assembly **210**, a frictional force  $F_{sub.fric}$  of the rack bar assembly **210**, and an inertial force of the rack bar assembly **210**. In this case, the inertial force of the rack bar assembly **210** may be expressed as a product of a mass  $M$  of the rack bar assembly **210** and an acceleration  $a$  of the rack bar assembly **210**.

(64)  $F_b \times R = F_{road} + F_{fric} + Ma$  [Equation1]

(65) Here,  $F_{sub.b}$  denotes the restoring force of the rack bar assembly **210**,  $R$  denotes the reduction ratio of the reducer,  $F_{sub.road}$  denotes the rack force of the rack bar assembly **210**,  $F_{sub.fric}$  denotes the frictional force of the rack bar assembly **210**,  $M$  denotes the mass of the rack bar assembly **210**, and  $a$  denotes the acceleration of the rack bar assembly **210**.

(66) In Equation 1, the restoring force  $F_{sub.b}$  of the rack bar assembly **210** may be calculated based on the output of the motor position sensor of the steering motor **240** and the output of the rack bar position sensor **220**. The reduction ratio  $R$  of the reducer and the mass  $M$  of the rack bar assembly **210** are predetermined. The acceleration  $a$  of the rack bar assembly **210** may be

calculated based on the output of the rack bar position sensor **220**. In addition, the frictional force  $F_{\text{sub.friction}}$  of the rack bar assembly **210** may be measured in advance.

(67) Therefore, the second processor **290** may acquire the rack force  $F_{\text{sub.road}}$  based on the restoring force  $F_{\text{sub.b}}$ , the reduction ratio  $R$ , the frictional force  $F_{\text{sub.friction}}$ , the mass  $M$ , and the acceleration  $a$  of the rack bar assembly **210** using Equation 2.

$$(68) \quad F_{\text{road}} = F_b \times R - F_{\text{fric}} - Ma \quad [\text{Equation2}]$$

(69) Here,  $F_{\text{sub.b}}$  denotes the restoring force of the rack bar assembly **210**,  $R$  denotes the reduction ratio of the reducer,  $F_{\text{sub.road}}$  denotes the rack force of the rack bar assembly **210**,  $F_{\text{sub.friction}}$  denotes the frictional force of the rack bar assembly **210**,  $M$  denotes the mass of the rack bar assembly **210**, and  $a$  denotes the acceleration of the rack bar assembly **210**.

(70) The second processor **290** may provide the communication signals corresponding to the rack force to the second communication interface **280** to transmit the rack force to the steering wheel actuator **100** via the communication network NT.

(71) As described above, the steering wheel actuator **100** may acquire the driver's steering intention through the steering wheel assembly **110** and transmit the target position corresponding to the steering intention to the steering rack actuator **200**. The steering rack actuator **200** may move the rack bar assembly **210** to the target position and transmit the rack force applied to the rack bar assembly **210** from the outside to the steering wheel actuator **100**. The steering wheel actuator **100** may provide the feedback torque corresponding to the rack force to the driver through the steering wheel assembly **110**.

(72) As described above, the rack force  $F_{\text{sub.road}}$  may be acquired by the restoring force  $F_{\text{sub.b}}$ , the reduction ratio  $R$ , the frictional force  $F_{\text{sub.friction}}$ , the mass  $M$ , and the acceleration  $a$  of the rack bar assembly **210**.

(73) Here, the restoring force, the reduction ratio, the mass, and the acceleration of the rack bar assembly **210** may not be greatly affected by the passage of time or external factors.

(74) On the other hand, the frictional force may vary depending on a temperature of the rack bar assembly **210** and/or a traveling distance of the vehicle. For example, a viscosity of a lubricant for smoothly moving the rack bar assembly **210** may increase in a low-temperature environment, thereby increasing the frictional force  $F_{\text{sub.friction}}$  of the rack bar assembly. In addition, foreign substances may flow into the rack bar assembly **210**, and the frictional force  $F_{\text{sub.friction}}$  of the rack bar assembly may increase due to the foreign substances.

(75) Due to the increase in the frictional force, the equation of motion of the rack bar assembly **210** may be changed as expressed in Equation 3.

$$(76) \quad F_b \times R = F_{\text{road\_real}} + F_{\text{fric}} + F_{\text{fric\_add}} + Ma \quad [\text{Equation3}]$$

(77) Here,  $F_{\text{sub.b}}$  denotes the restoring force of the rack bar assembly **210**,  $R$  denotes the reduction ratio of the reducer,  $F_{\text{sub.road\_real}}$  denotes an actual rack force of the rack bar assembly **210**,  $F_{\text{sub.friction}}$  denotes the predetermined frictional force of the rack bar assembly **210**,  $F_{\text{sub.friction\_add}}$  denotes the increased frictional force of the rack bar assembly **210**,  $M$  denotes the mass of the rack bar assembly **210**, and  $a$  denotes the acceleration of the rack bar assembly **210**.

(78) In addition, as expressed in Equation 2, the rack force of the rack bar assembly **210** may be acquired by subtracting the predetermined frictional force and the inertia force from the product of the restoring force and the reduction ratio.

(79) When the frictional force increases, the rack force of the rack bar assembly **210** may be acquired by Equation 4.

$$(80) \quad F_{\text{road\_esti}} = F_b \times R - F_{\text{fric}} - Ma + F_{\text{fric\_add}} = F_{\text{road\_real}} + F_{\text{fric\_add}} \quad [\text{Equation4}]$$

(81) Here,  $F_{\text{sub.road\_esti}}$  denotes the estimated rack force of the rack bar assembly **210**,  $F_{\text{sub.b}}$  denotes a restoring force of the rack bar assembly **210**,  $R$  denotes the reduction ratio of the reducer,  $F_{\text{sub.friction}}$  denotes a predetermined frictional force of the rack bar assembly **210**,  $F_{\text{sub.friction\_add}}$  denotes an increased frictional force of the rack bar assembly **210**,  $M$  denotes the mass of the rack

bar assembly **210**, a denotes the acceleration of the rack bar assembly **210**, and  $F_{sub.road\_real}$  denotes the actual rack force of the rack bar assembly **210**.

(82) When the frictional force of the rack bar assembly **210** increases, the estimated rack force  $F_{sub.road\_esti}$  of the rack bar assembly **210** may be acquired by the sum of the actual rack force  $F_{sub.road\_real}$  of the rack bar assembly **210** and the increased frictional force  $F_{sub.fric\_add}$  of the rack bar assembly **210**.

(83) As described above, due to the increase in the frictional force of the rack bar assembly **210**, the rack force  $F_{sub.road\_esti}$  greater than the actual rack force  $F_{sub.road\_real}$  may be estimated, and thus the feedback torque of the steering wheel actuator **100** may be increased. Therefore, different steering feeling may be provided to the driver.

(84) The steering apparatus **10** may identify the increase in the frictional force of the rack bar assembly **210** and the cause of the increase in the frictional force.

(85) FIG. 3 is a view illustrating one example of a test signal for identifying an increase in a frictional force by the steering apparatus according to one embodiment. FIG. 4 is a view illustrating one example of displacement of a rack bar assembly responding to the test signal illustrated in FIG. 3.

(86) The steering rack actuator **200** may provide a test signal corresponding to a predetermined target position to the steering driver **250** and/or the steering motor **240** in order to identify the increase in the frictional force of the rack bar assembly **210**.

(87) For example, as illustrated in FIG. 3, the steering rack actuator **200** may provide a triangular test signal corresponding to a target position to the steering driver **250** and/or the steering motor **240**. The target position may be changed to a triangular shape having a period of time point T4. A coordinate of the target position may linearly increase from an origin to position A between time point T0 and time point T1 (e.g., the target position may move in a left direction). The coordinate of the target position may linearly decrease from position A to position-A between time point T1 and time point T3 (e.g., the target position may move in the right direction). The target position may pass through the origin at time point T2. In addition, the target position may linearly increase to the origin between time point T3 and time point T4.

(88) In response to the test signal including the target position illustrated in FIG. 3, the steering motor **240** may move the rack bar assembly **210** as illustrated in FIG. 4. As illustrated in FIG. 4, the measured position of the rack bar assembly **210** may follow the target position. The steering rack actuator **200** may estimate a rack force based on a difference between the measured position of the rack bar assembly **210** and the target position illustrated in FIG. 4.

(89) A rack force corresponding to the target position illustrated in FIG. 3 at a predetermined speed and a predetermined road surface may be previously acquired by a prior experiment or the like. For example, the rack force corresponding to the target position illustrated in FIG. 3 in a state in which the vehicle has been stopped on asphalt may be acquired in advance by an experiment.

(90) The sum (hereinafter referred to as “reference rack force value”) of a maximum value of the previously acquired rack force at the predetermined speed and the predetermined road surface and an allowable error may be stored in the second memory **291** of the second processor **290**. For example, the previously acquired reference rack force value in the state in which the vehicle has been stopped on asphalt may be previously stored in the second memory **291**.

(91) The second processor **290** may provide the steering driver **250** with the steering control signal corresponding to the target position illustrated in FIG. 3 in the state in which the vehicle has been stopped on the asphalt road. The steering driver **250** may control the driving current supplied to the steering motor **240** according to the steering control signal.

(92) The second processor **290** may identify the position, the speed, and the acceleration of the rack bar assembly **210** based on the output of the rack bar position sensor **220** and acquire the maximum value of the rack force (hereinafter referred to as “estimated rack force value”) using the equation of motion.

(93) The second processor **290** may compare the estimated rack force value acquired using the equation of motion with the reference rack force value stored in the second memory **291**. The reference rack force value may represent the sum of the previously acquired maximum value of the rack force and the allowable error, and the estimated rack force value may represent the sum of the maximum value of the actual rack force and the increased frictional force. Therefore, the comparison between the estimated rack force value and the reference rack force value may represent a comparison between the increased frictional force and the allowable error.

(94) The second processor **290** may identify whether the measured rack force value is greater than the reference rack force value. That is, the second processor **290** may identify whether the increase in the frictional force is greater than the allowable error.

(95) The second processor **290** may identify that the frictional force of the rack bar assembly **210** has increased based on the measured rack force value greater than the reference rack force value.

(96) FIG. 5 is a view illustrating another example of the test signal for identifying the increase in the frictional force by the steering apparatus according to one embodiment.

(97) The test signal provided by the steering apparatus **10** to the steering motor **240** to identify the increase in the frictional force of the rack bar assembly **210** is not limited to the test signal illustrated in FIG. 3.

(98) For example, as illustrated in FIG. 5, the steering apparatus **10** may provide a trapezoidal test signal including a target position to the steering rack actuator **200**. The target position may be changed to a trapezoidal shape with a cycle of time point **T8**. A coordinate of the target position may linearly increase from an origin to position A between time point **T0** and time point **T1** (e.g., the target position may move in a left direction). The coordinate of the target position may maintain position A between time point **T1** and time point **T2**. The target position may linearly decrease from position A to the origin between time point **T2** and time point **T3** (e.g., the target position may move in the right direction). The target position may maintain the origin between time point **T3** and time point **T4**. The target position may linearly decrease from the origin to position-A between time point **T4** and time point **T5**. The target position may maintain position-A between time point **T5** and time point **T6**. The target position may increase linearly from position-A to the origin between time point **T6** and time point **T7**. In addition, the target position may maintain the origin between time point **T7** and time point **T8**.

(99) A rack force corresponding to the target position illustrated in FIG. 5 at a predetermined speed and a predetermined road surface may be previously acquired by a prior experiment or the like, and the sum (hereinafter referred to as “reference rack force value”) of the maximum value of the previously acquired rack force and the allowable error may be previously stored in the second memory **291** of the second processor **290**. In addition, the second processor **290** may identify that the frictional force of the rack bar assembly **210** has increased based on the measured rack force value greater than the reference rack force value.

(100) The steering apparatus **10** may also identify the increase in the frictional force of the steering wheel assembly **110** and the cause of the increase in the frictional force.

(101) The steering apparatus **10** may provide the feedback motor **140** with the test signal corresponding to the predetermined target position in order to identify the increase in the frictional force of the steering wheel assembly **110**.

(102) For example, the first processor **190** may provide the steering driver **250** with the triangular test signal corresponding to the target position and/or the steering motor **240** as illustrated in FIG. 3 or provide the feedback driver **150** and/or the feedback motor **140** with the trapezoidal test signal corresponding to the target position as illustrated in FIG. 5.

(103) The feedback motor **140** may provide the feedback torque to the steering wheel assembly **110** in response to the test signal of the first processor **190**, and the steering wheel assembly **110** may be rotated by the feedback torque.

(104) The first processor **190** may identify the feedback torque applied to the steering wheel

assembly **110** based on the driving current supplied to the feedback motor **140**. In addition, the feedback torque applied to the steering wheel assembly **110** in response to the test signal may be acquired by a prior experiment. The sum (hereinafter referred to as “reference feedback torque value”) of the previously acquired maximum value of the feedback torque and the allowable error may be previously stored in the first memory **191** of the first processor **190**.

(105) The angle sensor **120** may measure the rotation angle of the steering wheel assembly **110** and provide the electrical signal corresponding to the measured rotation angle to the first processor **190**. The first processor **190** may identify the rotation angle, a rotation rate, and a rotation angular acceleration of the steering wheel assembly **110** based on the output signal of the angle sensor **120**.

(106) The first processor **190** may acquire the feedback torque of the steering wheel assembly **110** from the rotation angle, the rotation rate, and the rotation angular acceleration of the steering wheel assembly **110** using an equation of rotation motion.

(107) The maximum value of the feedback torque (hereinafter referred to as “estimated feedback torque value”) acquired by the equation of the motion of the steering wheel assembly **110** may include the maximum value of the feedback torque applied to the steering wheel assembly **110** and the increased frictional force of the steering wheel assembly **110**.

(108) The first processor **190** may compare the estimated feedback torque value with the reference feedback torque value stored in the first memory **191**. The estimated feedback torque value may represent a maximum value of an actual feedback torque and the increased frictional force, and the reference feedback torque value may represent the sum of the previously acquired maximum value of the feedback torque and the allowable error. Therefore, the comparison between the estimated feedback torque value and the reference feedback torque value may represent a comparison between the increased friction and the allowable error.

(109) The first processor **190** may identify whether the estimated feedback torque value is greater than the reference feedback torque value. That is, the first processor **190** may identify whether the increase in the frictional force is greater than the allowable error.

(110) The first processor **190** may identify that the frictional force of the steering wheel assembly **110** has increased based on the estimated feedback torque value greater than the reference feedback torque value.

(111) As described above, the steering rack actuator **200** may identify that the frictional force of the rack bar assembly **210** has increased based on the measured rack force value greater than the reference rack force value and also identify that the frictional force of the steering wheel assembly **110** has increased based on the estimated feedback torque value greater than the reference feedback torque value.

(112) The steering apparatus **10** may identify the cause of the increase in the frictional force based on whether the frictional force of the rack bar assembly **210** has increased and whether the frictional force of the steering wheel assembly **110** has increased.

(113) For example, when the increase in the frictional force of the rack bar assembly **210** is identified and the increase in the frictional force of the steering wheel assembly **110** is identified, at least one of the first processor **190** or the second processor **290** may identify the increase in the frictional force due to a low temperature. Therefore, the steering apparatus **10** may output a message warning of a low temperature through an output device such as a display or the like of a vehicle.

(114) For example, when the increase in the frictional force of the rack bar assembly **210** is identified and the increase in the frictional force of the steering wheel assembly **110** is not identified, at least one of the first processor **190** or the second processor **290** may identify that the increase in the frictional force is due to the introduction of foreign substances into the rack bar assembly **210**. Therefore, the steering apparatus **10** may output a message guiding the driver to check the rack bar assembly **210** through the display or the like of the vehicle. In addition, the steering apparatus **10** may output a message warning the driver of the introduction of foreign

substances into the rack bar assembly **210** through the display or the like of the vehicle.

(115) For example, when the increase in the frictional force of the rack bar assembly **210** is not identified and the increase in the frictional force of the steering wheel assembly **110** is identified, at least one of the first processor **190** or the second processor **290** may identify the increase in the frictional force of the steering wheel assembly **110** due to a mechanical defect of the steering wheel assembly **110**. Therefore, the steering apparatus **10** may output a message guiding the driver to check the steering wheel assembly **110** through the display or the like of the vehicle. In addition, the steering apparatus **10** may output a message warning the driver of the mechanical defect of the steering wheel assembly **110** through the display or the like of the vehicle.

(116) For example, when the increase in the frictional force of the rack bar assembly **210** is not identified and the increase in the frictional force of the steering wheel assembly **110** is not identified, at least one of the first processor **190** or the second processor **290** may identify that an operation of the steering apparatus **10** is normal.

(117) As described above, the steering apparatus **10** may identify the increase in the frictional forces of the rack bar assembly **210** and/or the steering wheel assembly **110** and identify the causes of the increase in the frictional forces.

(118) Therefore, the steering apparatus **10** may provide the driver with an accurate state of the steering apparatus **10** so that the driver may easily maintain the steering apparatus **10** according to the causes of the increase in the frictional forces.

(119) The above description has been made that the steering apparatus **10** includes the steering wheel actuator **100** and the steering rack actuator **200**, and the steering wheel actuator **100** and the steering rack actuator **200** respectively include the first processor **190** and the second processor **290**.

(120) However, the control configuration of the steering apparatus **10** is not limited to the control configuration illustrated in FIGS. **1** and **2**.

(121) FIG. **6** is a view illustrating one example of a steering apparatus according to one embodiment. FIG. **7** is a view illustrating one example of a control configuration of the steering apparatus according to one embodiment.

(122) Referring to FIGS. **6** and **7**, the steering apparatus **10** may include the steering wheel actuator **100**, the steering rack actuator **200**, and a processor **300**.

(123) The steering wheel actuator **100** may acquire the driver's steering intention through the steering wheel and provide the steering wheel with the feedback torque corresponding to the rack force acting on the wheels of the vehicle.

(124) The steering wheel actuator **100** may include the steering wheel assembly **110**, the angle sensor **120**, the torque sensor **130**, the feedback motor **140**, and the feedback driver **150**. The steering wheel assembly **110**, the angle sensor **120**, the torque sensor **130**, the feedback motor **140**, and the feedback driver **150** do not correspond to essential components of the steering wheel actuator **100**, and at least some thereof may be omitted. In addition, the steering wheel assembly **110**, the angle sensor **120**, the torque sensor **130**, the feedback motor **140**, and the feedback driver **150** may be respectively the same as the steering wheel assembly, the angle sensor, the torque sensor, the feedback motor, and the feedback driver illustrated in FIGS. **1** and **2**.

(125) The steering rack actuator **200** may move the rack bar to steer the vehicle according to the driver's steering intention and identify the rack force applied to the rack bar.

(126) The steering rack actuator **200** may include the rack bar assembly **210**, the steering motor **240**, the steering driver **250**, and the rack bar position sensor **220**. The rack bar assembly **210**, the steering motor **240**, the steering driver **250**, and the rack bar position sensor **220** do not correspond to essential components of the steering rack actuator **200**, and at least some thereof may be omitted. In addition, the rack bar assembly **210**, the steering motor **240**, the steering driver **250**, and the rack bar position sensor **220** may be the same as the rack bar assembly, the steering motor, the steering driver, and the rack bar position sensor illustrated in FIGS. **1** and **2**.

(127) The processor **300** may be coupled to the steering wheel actuator **100** or the steering rack actuator **200**. In addition, the processor **300** may be physically separated from both the steering wheel actuator **100** and the steering rack actuator **200**.

(128) The processor **300** may be electrically connected to the steering wheel actuator **100** and the steering rack actuator **200**.

(129) The processor **300** may control the operation of the steering apparatus **10**. For example, the processor **300** may perform the roles of the first processor and the second processor illustrated in FIGS. **1** and **2**. In addition, the processor **300** may include a memory **301** for storing programs and data in order to implement the control of the operation of the steering apparatus **10**.

(130) The processor **300** may process the angle signal of the angle sensor **120** and/or the torque signal of the torque sensor **130** and identify the driver's steering intention based on a result of processing the angle signal and/or the torque signal. The processor **300** may identify the target position of the rack bar corresponding to the driver's steering intention and provide the steering control signal corresponding to the target position to the steering driver **250**. The steering driver **250** may control the driving current supplied to the steering motor **240** so that the rack bar assembly **210** follows the target position.

(131) The processor **300** may process the position signal of the rack bar position sensor **220** and identify the rack force based on a result of processing the position signal. The processor **300** may identify the feedback torque corresponding to the rack force and provide the feedback control signal corresponding to the feedback torque to the feedback driver **150**. The feedback driver **150** may control the driving current supplied to the feedback motor **140** to apply the feedback torque to the steering wheel assembly **110**.

(132) The processor **300** may identify the increase in the frictional forces of the rack bar assembly **210** and/or the steering wheel assembly **110** and the causes of the increase in the frictional forces.

(133) The processor **300** may provide the steering rack actuator **200** with a first test signal corresponding to the predetermined target position and identify the estimated rack force value based on the output signal of the rack bar position sensor **220**. The processor **300** may compare the estimated rack force value with a reference rack force value previously stored in the memory **301** and identify that the frictional force of the rack bar assembly **210** has increased based on the estimated rack force value greater than the reference rack force value.

(134) The processor **300** may provide the steering wheel assembly **110** with a second test signal corresponding to the predetermined feedback torque and identify the estimated feedback torque value based on the output signal of the angle sensor **120**. The processor **300** may compare the estimated feedback torque value with the reference feedback torque value previously stored in the memory **301** and identify that the frictional force of the steering wheel assembly **110** has increased based on the estimated feedback torque value greater than the reference feedback torque value.

(135) When the processor **300** identifies the increase in the frictional force of the rack bar assembly **210** and identifies the increase in the frictional force of the steering wheel assembly **110**, the steering apparatus **10** may identify the increase in the frictional force due to a low temperature.

(136) When the processor **300** identifies the increase in the frictional force of the rack bar assembly **210** and identifies no increase in the frictional force of the steering wheel assembly **110**, the steering apparatus **10** may identify the increase in the frictional force of the rack bar assembly due to the introduction of foreign substances into the rack bar assembly **210**.

(137) When the processor **300** identifies no increase in the frictional force of the rack bar assembly **210** and identifies the increase in the frictional force of the steering wheel assembly **110**, the steering apparatus **10** may identify the increase in the frictional force of the steering wheel assembly **110** due to the mechanical defect of the steering wheel assembly **110**.

(138) When the processor **300** identifies no increase in the frictional force of the rack bar assembly **210** and identifies no increase in the frictional force of the steering wheel assembly **110**, the steering apparatus **10** may identify that it is in the normal operation state.



(139) FIGS. **8** and **9** are views illustrating a method in which the steering apparatus identifies an increase in a frictional force and the cause of the increase in the frictional force.

(140) A method **1000** in which the steering apparatus **10** identifies the increase in the frictional forces and the causes of the increase in the frictional forces will be described with reference to FIGS. **8** and **9**.

(141) Operations to be described below do not correspond to essential operations of the method **1000** in which the steering apparatus **10** identifies the increase in the frictional forces and the causes of the increase in the frictional forces, and at least some of the operations may be omitted.

(142) The steering apparatus **10** may provide the first test signal to the steering rack actuator **200** (**1010**).

(143) For example, the processor **290** or **300** may provide the first test signal corresponding to the predetermined target position to the steering driver **250**. The steering driver **250** may control the driving current supplied to the steering motor **240** to move the rack bar assembly **210** according to the first test signal.

(144) The steering apparatus **10** may estimate the rack force of the rack bar assembly **210** (**1020**).

(145) For example, the processor **290** or **300** may identify the maximum value of the rack force (hereinafter referred to as “estimated rack force value”) applied to the rack bar assembly **210** based on the output signal of the rack bar position sensor **220**.

(146) The steering apparatus **10** may identify whether the estimated rack force value is greater than the reference rack force value (**1030**).

(147) For example, the processor **290** or **300** may previously store the maximum value of the rack force (hereinafter referred to as “reference rack force value”) corresponding to the first test signal. The processor **290** or **300** may compare the estimated rack force value with the reference rack force value and identify whether the estimated rack force value is greater than the reference rack force value.

(148) When it is identified that the estimated rack force value is greater than the reference rack force value (YES in **1030**), the steering apparatus **10** may provide the second test signal to the steering wheel actuator **100** (**1040**).

(149) For example, the processor **190** or **300** may provide the feedback driver **150** with the second test signal corresponding to the predetermined feedback torque. The feedback driver **150** may control the driving current supplied to the feedback motor **140** to provide the feedback torque according to the second test signal.

(150) The steering apparatus **10** may estimate the feedback torque of the steering wheel assembly **110** (**1050**).

(151) For example, the processor **190** or **300** may identify the maximum value of the feedback torque (hereinafter referred to as “estimated feedback torque value”) applied to the steering wheel assembly **110** based on the output signal of the angle sensor **120**.

(152) The steering apparatus **10** may identify whether the estimated feedback torque value is greater than the reference feedback torque value (**1060**).

(153) For example, the processor **190** or **300** may previously store the maximum value of the feedback torque (hereinafter referred to as “reference feedback torque value”) corresponding to the second test signal. The processor **190** or **300** may compare the estimated feedback torque value with the reference feedback torque value and identify whether the estimated feedback torque value is greater than the reference feedback torque value.

(154) When it is identified that the estimated feedback torque value is greater than the reference feedback torque value (YES in **1060**), the steering apparatus **10** may identify the increase in the frictional force due to the low temperature (**1070**).

(155) For example, the processor **190**, **290**, or **300** may identify the increase in the frictional force due to the low temperature based on identification of the increase in the frictional force of the rack bar assembly **210** and identification of the increase in the frictional force of the steering wheel

assembly **110**.

(156) When identifying the increase in the frictional force due to the low temperature, the steering apparatus **10** may output the message representing the increase in the frictional force of the steering apparatus **10** due to the low temperature through the display (e.g., a cluster or a navigation display) of the vehicle or a speaker of the vehicle.

(157) In addition, when identifying the increase in the frictional force due to the low temperature, the steering apparatus **10** may provide a diagnostic device of the vehicle with the message representing the increase in the frictional force of the steering apparatus **10** due to the low temperature.

(158) When it is identified that the estimated feedback torque value is not greater than the reference feedback torque value (NO in **1060**), the steering apparatus **10** may identify the increase in the frictional force of the steering rack actuator **200** due to the introduction of foreign substances (**1080**).

(159) For example, the processor **190**, **290**, or **300** may identify the increase in the frictional force of the rack bar assembly **210** due to the introduction of foreign substances into the rack bar assembly **210** based on identification of the increase in the frictional force of the rack bar assembly **210** and identification of the increase in the frictional force of the steering wheel assembly **110**.

(160) When identifying the increase in the frictional force due to the low temperature, the steering apparatus **10** may output the message representing the increase in the frictional force of the rack bar assembly **210** due to the introduction of foreign substances through the display (e.g., a cluster or a navigation display) of the vehicle or the speaker of the vehicle.

(161) In addition, when identifying the increase in the frictional force due to the low temperature, the steering apparatus **10** may provide the diagnostic device of the vehicle with the message representing the increase in the frictional force of the rack bar assembly **210** due to the introduction of foreign substances.

(162) When it is identified that the estimated rack force value is not greater than the reference rack force value (NO in **1030**), the steering apparatus **10** may provide the second test signal to the steering wheel actuator **100** (**1140**), estimate the feedback torque of the steering wheel assembly **110** (**1150**), and identify whether the estimated feedback torque value is greater than the reference feedback torque value (**1160**).

(163) Operations **1140**, **1150**, and **1160** may be the same as operations **1040**, **1050**, and **1060**, respectively.

(164) When it is identified that the estimated feedback torque value is greater than the reference feedback torque value (YES in **1160**), the steering apparatus **10** may identify the increase in the frictional force of the steering wheel assembly **110** due to the mechanical defect (**1170**).

(165) For example, the steering apparatus **10** may identify the increase in the frictional force of the steering wheel assembly **110** due to the mechanical defect of the steering wheel assembly **110** based on the processor **190**, **290**, or **300** that identify that there are no increase in the frictional force of the rack bar assembly **210** and the increase in the frictional force of the steering wheel assembly **110**.

(166) When identifying the increase in the frictional force due to the low temperature, the steering apparatus **10** may output the message representing the increase in the frictional force of the steering wheel assembly **110** due to the mechanical defect through the display (e.g., a cluster or a navigation display) of the vehicle or the speaker of the vehicle.

(167) In addition, when identifying the increase in the frictional force due to the low temperature, the steering apparatus **10** may provide the diagnostic device of the vehicle with the message representing the increase in the frictional force of the steering wheel assembly **110** due to the mechanical defect.

(168) When it is identified that the estimated feedback torque value is not greater than the reference feedback torque value (NO in **1160**), the steering apparatus **10** may identify that it is in a normal

operation state (1180).

(169) For example, the steering apparatus **10** may identify that the steering apparatus **10** is in the normal operation state based on the processors **190**, **290**, and **300** that identify that there are no increase in the frictional force of the rack bar assembly **210** and the increase in the frictional force of the steering wheel assembly **110**.

(170) As described above, the steering apparatus **10** may identify the increase in the frictional forces of the rack bar assembly **210** and/or the steering wheel assembly **110** and the causes of the increase in the frictional forces based on the estimated rack force value and the estimated feedback torque value.

(171) Therefore, the steering apparatus **10** may provide the driver with the accurate state of the steering apparatus **10** so that the driver may easily maintain the steering apparatus **10** according to the causes of the increase in the frictional forces.

(172) As is apparent from the above description, it is possible to provide a steering apparatus capable of detecting changes in frictional forces between internal members and a method of controlling the same. Therefore, the steering apparatus can allow a driver to feel the same steering feeling as at the time of an initial use of the steering apparatus.

(173) Meanwhile, disclosed embodiments may be implemented in the form of a recording medium in which instructions executable by a computer are stored. The instructions may be stored in the form of a program code, and when executed by a processor, program modules are generated to perform operations of the disclosed embodiments. The recording medium may be implemented as a computer-readable recording medium.

(174) The computer-readable recording medium includes any type of recording media in which instructions that can be decoded by a computer are stored. For example, there may be a ROM, a RAM, a magnetic tape, a magnetic disk, a flash memory, an optical data storage device, etc.

(175) A device-readable storage medium may be provided in the form of a non-transitory storage medium. Here, “non-transitory storage medium” is a tangible device and only means not including a signal (e.g., electromagnetic waves), and this term does not distinguish between cases in which data is stored semi-permanently and temporarily in the storage medium. For example, “non-temporary storage medium” may include a buffer in which data is temporarily stored.

(176) As described above, the disclosed embodiments have been described with reference to the accompanying drawings. Those skilled in the art to which the present disclosure pertains will understand that the present disclosure can be carried out in the form different from those of the disclosed embodiments even without changing the technical spirit or essential features of the present disclosure. The disclosed embodiments are illustrative and should not be construed as being limited.

## Claims

1. A steering apparatus comprising: a feedback motor including a rotation shaft connected to a steering wheel provided in a vehicle; an angle sensor configured to output an angle signal corresponding to a rotation displacement of the steering wheel; a steering motor including a rotation shaft connected to a rack bar provided in the vehicle; a position sensor configured to output a position signal corresponding to a linear displacement of the rack bar; and at least one processor configured to: control the steering motor to linearly move the rack bar based on predetermined target positions, identify a rack force applied to the rack bar based on the position signal of the position sensor, control the feedback motor based on a predetermined feedback torque; identify a feedback torque applied to the steering wheel based on the angle signal of the angle sensor, and provide an output device of the vehicle with an electrical signal indicating whether an increase in a frictional force of at least one of the rack bar or the steering wheel occurs based on the identified rack force and the identified feedback torque.

2. The steering apparatus of claim 1, wherein the at least one processor is configured to: identify the increase in the frictional force of the rack bar based on the identified rack force being greater than a predetermined reference rack force; and identify the increase in the frictional force of the steering wheel based on the identified feedback torque being greater than a predetermined reference feedback torque.
3. The steering apparatus of claim 1, wherein the at least one processor is configured to provide the electrical signal to the output device to output a message warning of a low temperature causing the increases in the frictional forces of the rack bar and the steering wheel based on the identified rack force being greater than a predetermined reference rack force and the identified feedback torque being greater than a predetermined reference feedback torque.
4. The steering apparatus of claim 1, wherein the at least one processor is configured to provide the electrical signal to the output device to output a message warning of introduction of foreign substances into the rack bar based on the identified rack force being greater than a predetermined reference rack force and the identified feedback torque being not greater than a predetermined reference feedback torque.
5. The steering apparatus of claim 1, wherein the at least one processor is configured to provide the electrical signal to the output device to output a message warning of a mechanical defect of the steering wheel based on the identified rack force being not greater than a predetermined reference rack force and the identified feedback torque being greater than a predetermined reference feedback torque.
6. The steering apparatus of claim 1, wherein the at least one processor is configured to identify a normal operation of the steering apparatus based on the identified rack force being not greater than a predetermined reference rack force and the identified feedback torque being not greater than a predetermined reference feedback torque.
7. The steering apparatus of claim 1, wherein the predetermined target positions comprise target positions whose displacements from an origin change in a form of a triangular or trapezoidal, and the predetermined feedback torque comprises a feedback torque whose magnitude changes in a form of a triangular or trapezoidal.
8. The steering apparatus of claim 1, wherein the at least one processor comprises: a first processor electrically connected to the feedback motor and the angle sensor; and a second processor electrically connected to the steering motor and the position sensor, and the first processor is configured to communicate with the second processor.
9. A method of controlling a steering apparatus including a steering wheel provided in a vehicle and a rack bar connected to a rotation shaft of the wheel provided in the vehicle, the method comprising: controlling a linear movement of the rack bar based on predetermined target positions; identifying a rack force applied to the rack bar based on a position signal of a position sensor, the position sensor configured to output the position signal corresponding to a linear displacement of the rack bar; controlling rotation of the steering wheel based on a predetermined feedback torque; identifying a feedback torque applied to the steering wheel based on an angle signal of an angle sensor, the angle sensor configured to output the angle signal corresponding to a rotation displacement of the steering wheel; and providing an output device of the vehicle with an electrical signal indicating whether an increase in a frictional force of at least one of the rack bar or the steering wheel occurs based on the identified rack force and the identified feedback torque.
10. The method of claim 9, wherein the providing of the electrical signal corresponding to the increase in the frictional force of the at least one of the rack bar or the steering wheel comprises: identifying the increase in the frictional force of the rack bar based on the identified rack force being greater than a predetermined reference rack force; and identifying the increase in the frictional force of the steering wheel based on the identified feedback torque being greater than a predetermined reference feedback torque.
11. The method of claim 9, further comprising providing the electrical signal to the output device to

output a message warning of a low temperature causing the increases in the frictional forces of the rack bar and the steering wheel based on the identified rack force being greater than a predetermined reference rack force and the identified feedback torque being greater than a predetermined reference feedback torque.

12. The method of claim 9, further comprising providing the electrical signal to the output device to output a message warning of introduction of foreign substances into the rack bar based on the identified rack force being greater than a predetermined reference rack force and the identified feedback torque being not greater than a predetermined reference feedback torque.

13. The method of claim 9, further comprising providing the electrical signal to the output device to output a message warning of a mechanical defect of the steering wheel based on the identified rack force being not greater than a predetermined reference rack force and the identified feedback torque being greater than a predetermined reference feedback torque.

14. The method of claim 9, further comprising identifying that a normal operation of the steering apparatus based on the identified rack force being not greater than a predetermined reference rack force and the identified feedback torque being not greater than a predetermined reference feedback torque.

15. The method of claim 9, wherein the predetermined target positions comprise target positions whose displacements from an origin change in a form of a triangular or trapezoidal, and the predetermined feedback torque comprises a feedback torque whose magnitude changes in a form of a triangular or trapezoidal.

16. A steering apparatus comprising: a steering wheel actuator; and a steering rack actuator, wherein the steering wheel actuator includes: a feedback motor including a rotation shaft connected to a steering wheel provided in a vehicle; an angle sensor configured to output an angle signal corresponding to a rotation displacement of the steering wheel; and a first processor configured to transmit a target position corresponding to the angle signal to the steering rack actuator and control a feedback motor to apply a feedback torque corresponding to a rack force of the steering wheel actuator to the steering wheel, wherein the steering rack actuator includes: a steering motor including a rotation shaft connected to a rack bar provided in the vehicle; a position sensor configured to output a position signal corresponding to a linear displacement of the rack bar assembly; and a second processor configured to control the steering motor to linearly move the rack bar based on the target position and identify a rack force applied to the rack bar based on the position signal, wherein the first processor is configured to control the feedback motor based on a predetermined feedback torque and provide an electrical signal indicating whether an increase in a frictional force of the steering wheel occurs to an output device of the vehicle based on a feedback torque value identified based on the angle signal, and the second processor is configured to control the steering motor based on predetermined target positions and provide an electrical signal indicating whether an increase in a frictional force of the rack bar occurs to the output device of the vehicle based on a rack force value identified based on the position signal.

17. The steering apparatus of claim 16, wherein at least one processor of the first processor or the second processor is configured to provide the electrical signal to the output device to output a message warning of a low temperature causing the increases in the frictional forces of the rack bar and the steering wheel based on the identified rack force being greater than a predetermined reference rack force and the identified feedback torque being greater than a predetermined reference feedback torque.

18. The steering apparatus of claim 16, wherein at least one processor of the first processor or the second processor is configured to provide the electrical signal to the output device to output a message warning of introduction of foreign substances into the rack bar based on the identified rack force being greater than a predetermined reference rack force and the identified feedback torque being not greater than a predetermined reference feedback torque.

19. The steering apparatus of claim 16, wherein at least one processor of the first processor or the

second processor is configured to provide the electrical signal to the output device to output a message warning of a mechanical defect of the steering wheel based on the identified rack force being not greater than a predetermined reference rack force and the identified feedback torque being greater than a predetermined reference feedback torque.

20. The steering apparatus of claim 16, wherein at least one processor of the first processor or the second processor is configured to identify a normal operation of the steering apparatus based on the identified rack force being not greater than a predetermined reference rack force and the identified feedback torque being not greater than a predetermined reference feedback torque.

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