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Lee et al.

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(54) **STEERING CONTROL DEVICE AND METHOD**

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B62D 6/00 (2006.01)

(52) **U.S. Cl.**
CPC ***B62D 6/008*** (2013.01)

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USPC 701/41, 42, 43, 44
See application file for complete search history.

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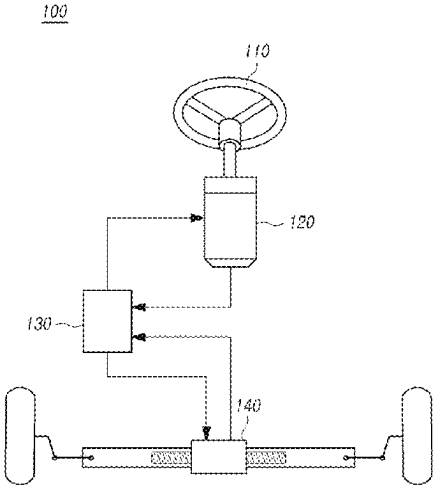
(57) **ABSTRACT**

The present embodiments relate to a steering control device and method and may provide a steering control device and method capable of compensating for the effect on the increased friction level of the road wheel actuator (RWA) mechanism at a low temperature in a steer by wire (SBW) system. In particular, there may be provided a steering control device and method capable for compensating for heavy steering that the driver may feel at low temperature by determining a friction level at a low temperature while driving according to a preset compensation condition and compensating for rack force information with respect to the friction level.

20 Claims, 8 Drawing Sheets



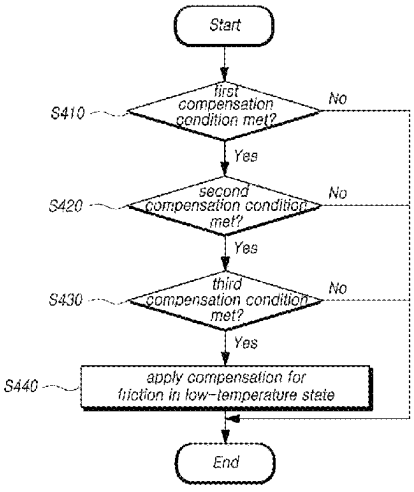


FIG. 1

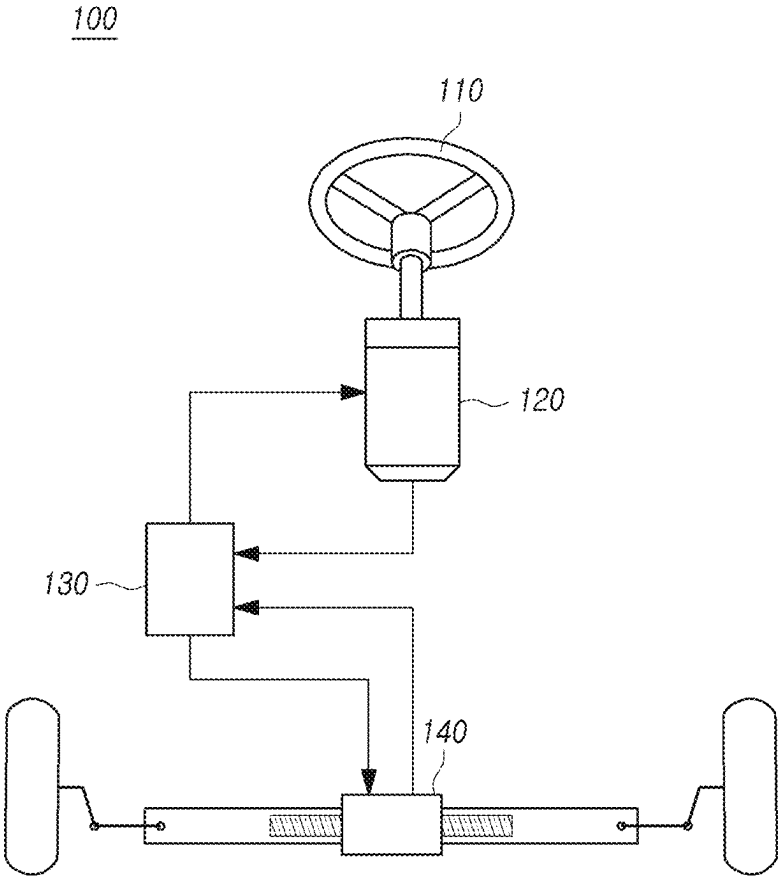


FIG.2

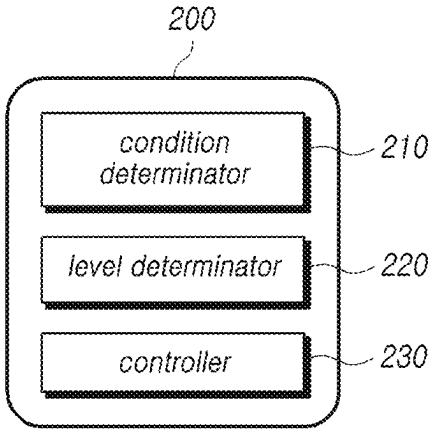

200
condition determinator
210
level determinator
220
controller
230

FIG.3

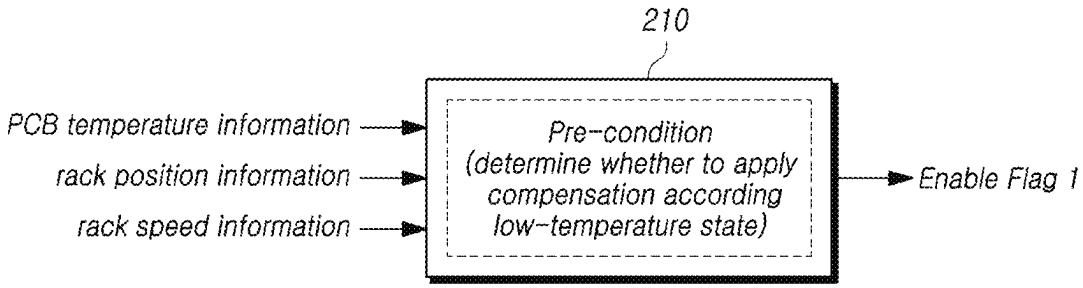

210
PCB temperature information
rack position information
rack speed information
Pre-condition
(determine whether to apply
compensation according
low-temperature state)
Enable Flag 1

FIG.4

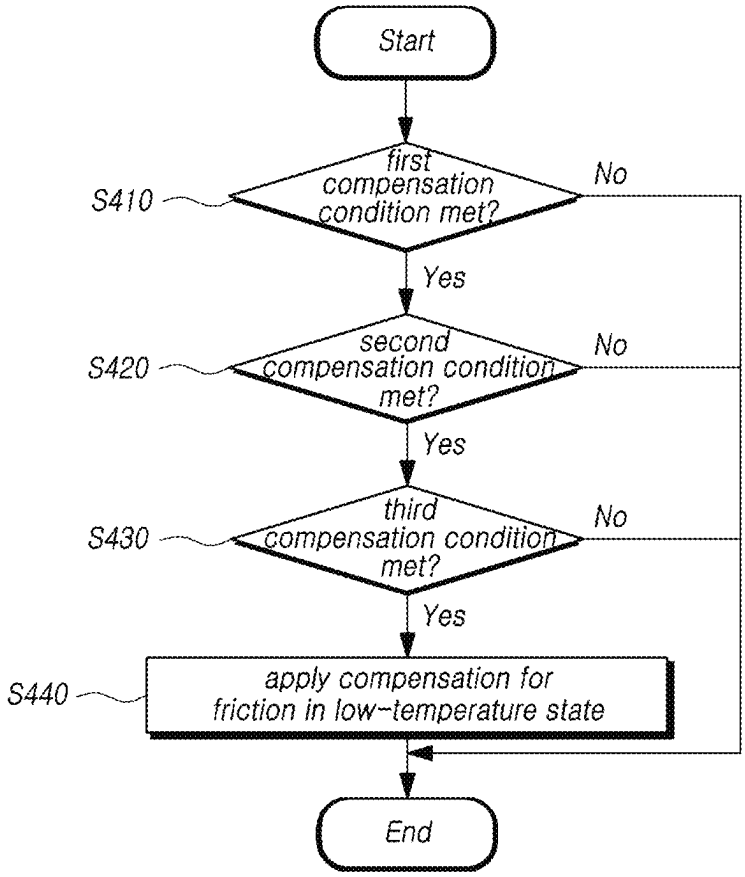

Start
S410
first compensation condition met?
No
Yes
S420
second compensation condition met?
No
Yes
S430
third compensation condition met?
No
Yes
S440
apply compensation for friction in low-temperature state
End

FIG.5

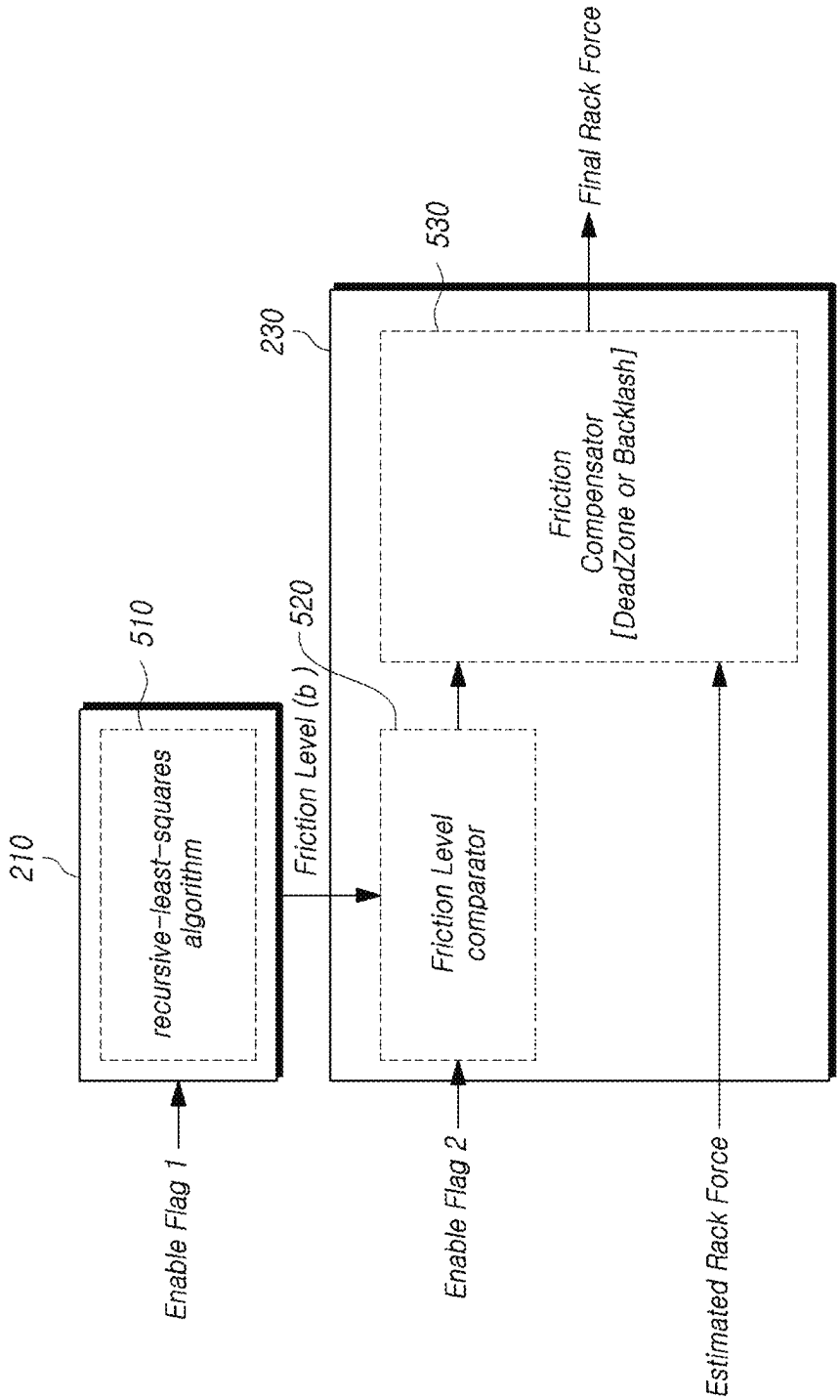
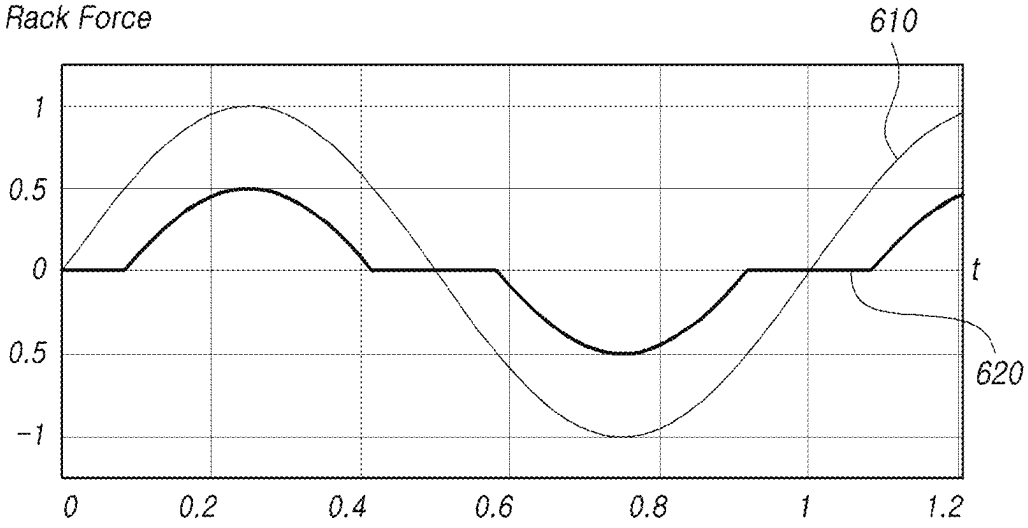
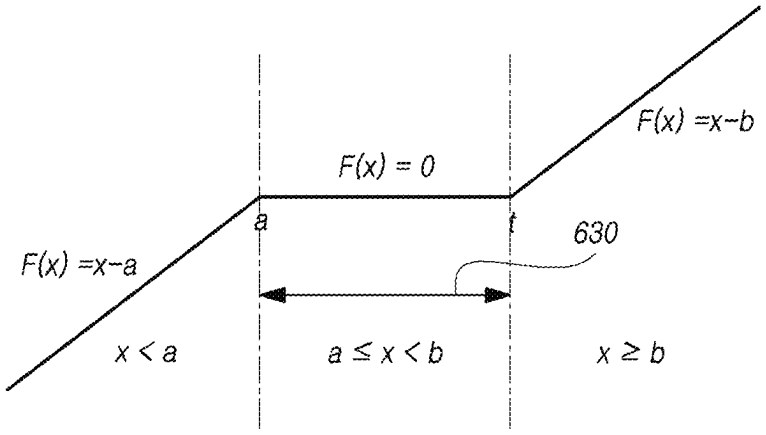

210
recursive-least-squares algorithm
510
Friction Level (b)
520
230
Friction Level comparator
Friction Compensator [DeadZone or Backlash]
530
Final Rack Force
Enable Flag 1
Enable Flag 2
Estimated Rack Force

FIG.6

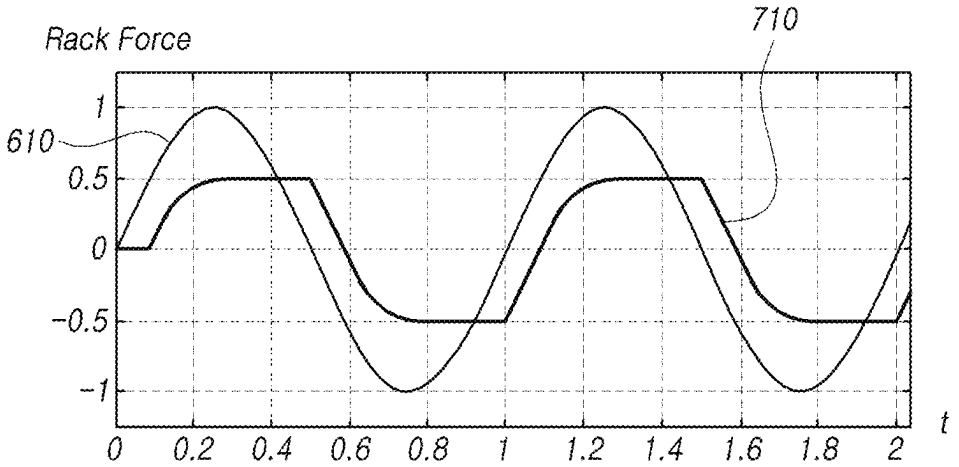

Rack Force
610
1
0.5
0
0.5
-1
0
0.2
0.4
0.6
0.8
1
1.2
t
620

(a)

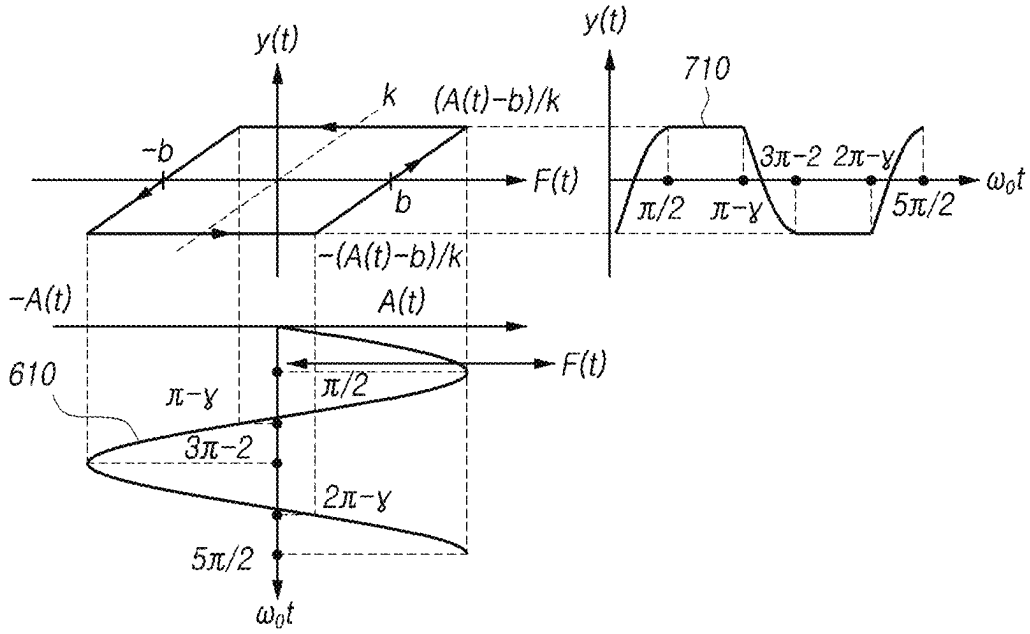

F(x) =x-b
F(x) = 0
F(x) =x-a
a
t
630
x < a
a ≤ x < b
x ≥ b

(b)

FIG. 7

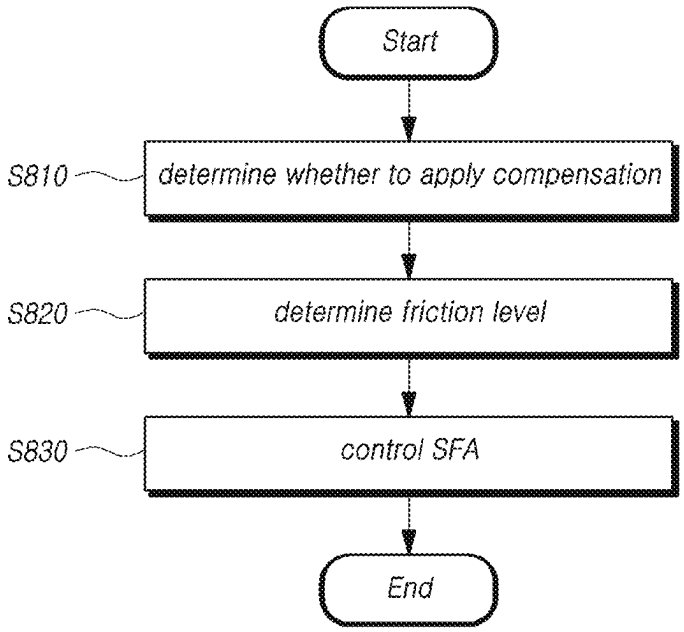

Rack Force
710
610
1
0.5
0
-0.5
-1
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
t

(a)


y(t)
k
(A(t)-b)/k
-b
b
F(t)
-(A(t)-b)/k
-A(t)
A(t)
610
π-γ
π/2
3π-2
2π-γ
5π/2
ω0t
y(t)
710
3π-2
2π-γ
π/2
π-γ
5π/2
ω0t

(b)

FIG. 8


Start
S810
determine whether to apply compensation
S820
determine friction level
S830
control SFA
End

STEERING CONTROL DEVICE AND METHOD

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority from Korean Patent Application No. 10-2022-0106029, filed on Aug. 24, 2022, which is hereby incorporated by reference for all purposes as if fully set forth herein.

BACKGROUND

Field

The present embodiments relate to a steering control device and method.

Description of Related Art

The vehicle's steer by wire (SBW) system may be a system that allows the vehicle to be steered by an electric motor instead of removing mechanical linking devices, such as steering columns, universal joints, or pinion shafts between the steering wheel and wheels. Unlike general-purpose steering systems, the steer by wire (SBW) system may be composed of a steering feedback actuator (SFA) and a road wheel actuator (RWA). Further, the steer by wire (SBW) system needs to generate an appropriate steering reaction force from a motor installed on the steering wheel in order for the driver to have a similar sense of steering to that of the conventional steering system. Specifically, due to no mechanical linkage between the steering rack gear and the steering column, the steer by wire (SBW) system may estimate the rack force based on the signal from the road wheel actuator (RWA) and transmit it to the steering feedback actuator (SFA), transferring road information and vehicle status to the driver.

However, if the temperature changes in the steer by wire (SBW) system, the friction level of the road wheel actuator (RWA) mechanism may be varied. For example, in a low-temperature state, the friction level may rise due to a change in the physical property of the grease applied to, e.g., the bearings of the road wheel actuator (RWA) mechanism. In other words, in the steer by wire (SBW) system, as the friction level of the road wheel actuator (RWA) mechanism rises in a low-temperature state, the hysteresis of the rack force may increase, causing the driver to feel heavier steering than in a room-temperature state.

Therefore, the steer by wire (SBW) system requires a technique for compensating for the effect on the increased friction level of the road wheel actuator (RWA) mechanism at low temperature to prevent such an influence.

BRIEF SUMMARY

In the foregoing background, the present embodiments may provide a steering control device and method capable of compensating for the effect on the increased friction level of the road wheel actuator (RWA) mechanism at a low temperature in a steer by wire (SBW) system.

In an aspect, the present embodiments may provide a steering control device applied to a steer by wire (SBW) system of a vehicle, comprising a condition determinator configured to determine whether to apply compensation for friction generated in a mechanism of a road wheel actuator (RWA) in a low-temperature state based on printed circuit board (PCB) temperature information, rack position information, and rack speed information according to a preset compensation condition, a level determinator configured to determine a friction level based on the rack force information according to a result of the determination by the condition determinator, and a controller configured to convert the rack force information into final rack force information by compensating for the rack force information based on the determined friction level and control a steering feedback actuator (SFA) based on the final rack force information.

In another aspect, the present embodiments may provide a steering control method applied to a steer by wire (SBW) system of a vehicle, comprising determining whether to apply compensation for friction generated in a mechanism of a road wheel actuator (RWA) in a low-temperature state based on PCB temperature information, rack position information, and rack speed information according to a preset compensation condition, determining a friction level based on the rack force information according to a result of the determination of whether to apply the compensation, and converting the rack force information into final rack force information by compensating for the rack force information based on the determined friction level and controlling a steering feedback actuator (SFA) based on the final rack force information.

According to the present embodiments, there may be provided a steering control device and method capable of compensating for the effect on the increased friction level of the road wheel actuator (RWA) mechanism at a low temperature in a steer by wire (SBW) system.

DESCRIPTION OF DRAWINGS

The above and other objects, features, and advantages of the disclosure will be more clearly understood from the following detailed description, taken in conjunction with the accompanying drawings, in which:

FIG. **1** is a view illustrating a chemical formula of a steer by wire (SBW) system to which a steering control device is applied according to an embodiment of the disclosure;

FIG. **2** is a view illustrating a configuration of a steering control device according to an embodiment of the disclosure;

FIG. **3** is a view illustrating a condition determinator of a steering control device according to an embodiment of the disclosure;

FIG. **4** is a flowchart illustrating an operation for determining whether a condition determinator of a steering control device applies compensation according to an embodiment of the disclosure;

FIG. **5** is a view illustrating a level determinator and a controller of a steering control device according to an embodiment of the disclosure;

FIGS. **6** and **7** are views illustrating an operation for changing into final rack force information by a controller of a steering control device according to an embodiment of the disclosure; and

FIG. **8** is a flowchart illustrating a steering control method according to an embodiment of the disclosure.

DETAILED DESCRIPTION

In the following description of examples or embodiments of the disclosure, reference will be made to the accompanying drawings in which it is shown by way of illustration specific examples or embodiments that can be implemented,

and in which the same reference numerals and signs can be used to designate the same or like components even when they are shown in different accompanying drawings from one another. Further, in the following description of examples or embodiments of the disclosure, detailed descriptions of well-known functions and components incorporated herein will be omitted when it is determined that the description may make the subject matter in some embodiments of the disclosure rather unclear. The terms such as "including", "having", "containing", "constituting" "make up of", and "formed of" used herein are generally intended to allow other components to be added unless the terms are used with the term "only". As used herein, singular forms are intended to include plural forms unless the context clearly indicates otherwise.

Terms, such as "first", "second", "A", "B", "(A)", or "(B)" may be used herein to describe elements of the disclosure. Each of these terms is not used to define essence, order, sequence, or number of elements etc., but is used merely to distinguish the corresponding element from other elements.

When it is mentioned that a first element "is connected or coupled to", "contacts or overlaps" etc. a second element, it should be interpreted that, not only can the first element "be directly connected or coupled to" or "directly contact or overlap" the second element, but a third element can also be "interposed" between the first and second elements, or the first and second elements can "be connected or coupled to", "contact or overlap", etc. each other via a fourth element. Here, the second element may be included in at least one of two or more elements that "are connected or coupled to", "contact or overlap", etc. each other.

When time relative terms, such as "after," "subsequent to," "next," "before," and the like, are used to describe processes or operations of elements or configurations, or flows or steps in operating, processing, manufacturing methods, these terms may be used to describe non-consecutive or non-sequential processes or operations unless the term "directly" or "immediately" is used together.

In addition, when any dimensions, relative sizes etc. are mentioned, it should be considered that numerical values for an elements or features, or corresponding information (e.g., level, range, etc.) include a tolerance or error range that may be caused by various factors (e.g., process factors, internal or external impact, noise, etc.) even when a relevant description is not specified. Further, the term "may" fully encompasses all the meanings of the term "can".

FIG. **1** is a view illustrating a chemical formula of a steer by wire (SBW) system to which a steering control device is applied according to an embodiment of the disclosure.

Referring to FIG. **1**, an SBW system to which a steering control device according to an embodiment of the disclosure is applied may be described. For example, the steer by wire (SBW) system **100** may be a system in which there is no mechanical linkage between the steering wheel **110** and the rack **140**, unlike an electronic power steering (EPS) system which is a conventional steering control system. For example, the upper end of the SBW system **100** may include a reaction force motor for applying a steering reaction force, and a steering feedback actuator including a steering torque sensor, a steering angle sensor, and the like mounted on the steering column. Further, the lower end of the SBW system **100** may include a road wheel actuator (RWA) including a steering driving motor or a driving actuator for driving a rack bar.

In other words, in the SBW system **100**, a column connected to the steering wheel **110** may be coupled to the steering feedback actuator (SFA) **120** capable of applying a steering reaction force to the steering wheel **110**. The rack **140** may be coupled to a road wheel actuator (RWA) **130** for controlling the front wheels. The steering feedback actuator **120** may be coupled with a reaction force motor for applying the steering reaction force, and the road wheel actuator **130** may be coupled with a steering driving motor for controlling the front wheel by moving the rack. Since the SBW system **100** does not have a mechanical linkage between the steering wheel **110** and the rack **140**, although the rack gear receives an external force when the vehicle is steered, the force may not be transferred to the steering wheel. Accordingly, a separate steering reaction force generator may be required to provide the driver with a similar sense of steering to that of the EPS, which is the conventional steering control system having mechanical linkage, by generating an appropriate steering reaction force when the vehicle is steered. The steering reaction force or the steering reaction torque may be a force or torque applied to the steering wheel connected to the upper-end device according to the movement of the rack bar of the lower-end device in which actual steering is performed.

Specifically, due to no mechanical linkage between the steering wheel and the rack, the SBW system **100** may not use the steering reaction force calculation method used in the conventional EPS, and the steering reaction force generator of the SBW system **100** may need to control the steering feedback actuator by deriving the steering reaction force as a function of the rack force. Moreover, in the low-temperature state, as the friction level of the road wheel actuator (RWA) mechanism included in the SBW system **100** increases, the driver may feel heavier steering than in a room-temperature state. Accordingly, the SBW system **100** may need to compensate for the effect on the friction level that increases in the low-temperature state.

FIG. **2** is a view illustrating a configuration of a steering control device according to an embodiment of the disclosure.

Referring to FIG. **2**, a steering control device **200** according to an embodiment of the disclosure may include a condition determinator **210**, a level determinator **220**, and a controller **230**. As an example, a steering control device **200** applied to a steer by wire (SBW) system of a vehicle may comprise a condition determinator **210** determining whether to apply compensation for friction generated in a mechanism of a road wheel actuator (RWA) in a low-temperature state based on printed circuit board (PCB) temperature information, rack position information, and rack speed information according to a preset compensation condition, a level determinator **220** determining a friction level based on the rack force information according to a result of the determination by the condition determinator, and a controller **230** converting the rack force information into final rack force information by compensating for the rack force information based on the determined friction level and controlling a steering feedback actuator (SFA) based on the final rack force information.

The condition determinator **210** of the steering control device **200** according to an embodiment may determine whether to apply compensation for friction occurring in the mechanism of the road wheel actuator (RWA) in the low-temperature state. For example, the condition determinator **210** may determine whether to apply compensation for friction occurring in the mechanism of the road wheel actuator in the low-temperature state based on the PCB temperature information, the rack position information, and the rack speed information according to a predetermined

compensation condition. For example, the condition determinator **210** may sequentially determine a first compensation condition, a second compensation condition, and a third compensation condition included in the compensation condition. If all of the first compensation condition, the second compensation condition, and the third compensation condition are met, the condition determinator **210** may determine to apply compensation for friction. Here, it may be determined that the first compensation condition is that the PCB temperature information is less than or equal to a preset reference temperature. The second compensation condition may be determined when the first compensation condition is met, and it may be determined that the second compensation condition is that the absolute value of the rack position information is less than or equal to a preset reference position. The third compensation condition may be determined when the first compensation condition and the second compensation condition are met, and it may be determined that the third compensation condition is that the absolute value of the rack speed information is less than or equal to a preset reference speed.

The level determinator **220** of the steering control device **200** according to an embodiment may determine the friction level based on the rack force information according to the determination result of the condition determinator **210**. For example, when it is determined to apply compensation for friction, the level determinator **220** may determine the friction level based on the rack force information. For example, the level determinator **220** may estimate a parameter through a recursive-least-squares algorithm using rack force information as an input and determine the estimated parameter as a friction level. Specifically, the level determinator **220** may compare the input rack force information calculated by the recursive-least-squares algorithm with the output rack force information calculated with the estimated parameter. In this case, the estimated parameter b may be determined as the friction level. In other words, the level determinator **220** may determine the friction level by estimating a parameter that is a specific coefficient of the polynomial based on the recursive-least-squares algorithm using the rack force information as an input.

The controller **230** of the steering control device **200** according to an embodiment may control the steering feedback actuator (SFA) based on the final rack force information where the compensation for friction has been applied according to the low temperature. For example, the controller **230** may compensate for the rack force information based on the determined friction level and convert the rack force information into final rack force information. The controller **230** may control the steering feedback actuator (SFA) based on the final rack force information. For example, the controller **230** may compare the friction level with a preset reference friction level to compensate for the rack force information only when the friction level is equal to or greater than the reference friction level. Here, the reference friction level may be calculated from rack force information estimated during a time corresponding to a compliance zone in the room-temperature state. Also, e.g., the controller **230** may compensate for the estimated rack force information to reduce the increased friction as the controller **230** becomes in the low-temperature state and convert the rack force information into the final rack force information. Further, the controller **230** may configure a friction compensator including at least one of a dead zone and a back lash based on the estimated rack force information and apply the friction compensator to convert the rack force information into the final rack force information. Specifically, the controller may set an arbitrary range as the dead zone based on the estimated rack force information, and convert into the final rack force information by lowering the estimated rack force information using the dead zone. Accordingly, the converted final rack force information may be that the set dead zone range is maintained as 0, and the other ranges are a value reduced by a predetermined size with respect to the estimated rack force information. However, the dead zone and the back lash are examples of the friction compensator, but are not limited thereto.

FIG. **3** is a view illustrating a condition determinator of a steering control device according to an embodiment of the disclosure.

Referring to FIG. **3**, the condition determinator **210** of the steering control device **200** according to an embodiment of the disclosure may determine whether to apply compensation according to a low-temperature state. For example, the condition determinator **210** may determine whether to apply compensation for friction occurring in the mechanism of the road wheel actuator in the low-temperature state based on the PCB temperature information, the rack position information, and the rack speed information according to the compensation condition. Here, the compensation condition may be a pre condition set to determine a friction level at a low temperature while driving using the PCB temperature information and the vehicle information measured by the sensor at room temperature and determine whether to apply compensation.

For example, the condition determinator **210** may receive and obtain sensing information from at least one of a steering angle sensor detecting a change in the rotation of the steering shaft that varies depending on manipulation of the driver's steering wheel **110**, a torque sensor detecting the torque of the reaction force motor, a vehicle velocity sensor detecting the vehicle velocity, a rack position sensor installed on the rack bar to detect rack position information, and a motor position sensor of the reaction force motor, for the PCB temperature information, rack position information, and rack speed information. As a specific example, the condition determinator **210** may measure rack position information using the rack position sensor installed on the rack bar, and obtain rack speed information by differentiating the measured rack position information. Alternatively, the condition determinator **210** may measure rotation amount information about the motor using an encoder of the motor driving the rack bar, and obtain rack position information and rack speed information from the measured motor rotation amount information. As another specific example, the condition determinator **210** may obtain PCB temperature information from the controller using CAN communication.

Further, e.g., the condition determinator **210** may sequentially determine the measured PCB temperature information, rack position information, and rack speed information according to the first compensation condition, the second compensation condition, and the third compensation condition included in the compensation condition, and when all of the compensation conditions are met, determine to apply compensation for friction.

When the condition determinator **210** determines to apply compensation for the friction generated in the mechanism of the road wheel actuator in a low-temperature state according to the compensation condition, an enable flag **1** may be generated for applying a compensation logic. Accordingly, only when an enable flag is generated, the next operations of determining the friction level and compensating for rack force information may be performed. A detailed description

of sequentially determining the compensation condition by the condition determinator **210** is made below with reference to FIG. **4**.

FIG. **4** is a flowchart illustrating an operation for determining whether a condition determinator of a steering control device applies compensation according to an embodiment of the disclosure.

Referring to FIG. **4**, an operation in which the condition determinator **210** of the steering control device **200** according to an embodiment of the disclosure determines whether to apply compensation for friction in a low-temperature state may be described. As an example, the condition determinator **210** of the steering control device **200** may determine whether the first compensation condition is met (S**410**). For example, the condition determinator **210** may determine that the first compensation condition is met if the PCB temperature information is a preset reference temperature or less. Here, the reference temperature may be set to a temperature at which the friction level occurring in the mechanism of the road wheel actuator rises as the temperature reduces so that the hysteresis of the rack force starts to increase. Specifically, the reference temperature may be preset to −10° C., but is not limited thereto as long as it is a temperature at which the friction level increases due to a change in the physical properties of the mechanism as the temperature decreases. In other words, when the PCB temperature information exceeds the predetermined reference temperature according to the first compensation condition, the condition determinator **210** may withhold application of compensation for friction. On the other hand, if the PCB temperature information is less than or equal to the predetermined reference temperature, the condition determinator **210** may determine that the first compensation condition is met and may thus determine the second compensation condition.

For example, if the first compensation condition is met, the condition determinator **210** of the steering control device **200** may determine whether the second compensation condition is met (S**420**). For example, if the first compensation condition is met, the condition determinator **210** may determine that the second compensation condition is met if the absolute value of the rack position information is less than or equal to a preset reference position. Here, the reference position may be set to a position for detecting compensation according to the low temperature. Specifically, the reference position may be preset in a small range of 1 mm, but is not limited thereto as long as it is a position that may be a reference for whether to apply compensation according to low temperature. Further, the condition determinator **210** may receive and obtain rack position information from a rack position sensor installed on the rack bar. The rack position information may be information measured in a tiny operation area to minimize the influence on other parts. In other words, if the absolute value of the rack position information exceeds the preset reference position according to the second compensation condition, the condition determinator **210** may withhold the application of compensation for friction. In contrast, if the absolute value of the rack position information is less than or equal to the preset reference position, the condition determinator **210** may determine that the second compensation condition is met and may thus determine the third compensation condition.

For example, if the first compensation condition and the second compensation condition are met, the condition determinator **210** of the steering control device **200** may determine whether the third compensation condition is met (S**430**). For example, when the first compensation condition and the second compensation condition are met, the condition determinator **210** may determine that the third compensation condition is met if the absolute value of the rack speed information is less than or equal to a preset reference speed. Here, the reference speed may be set to a speed at which compensation according to the low temperature is detected.

Specifically, the reference speed may be preset at a speed of 1 to 2 mm/s, but is not limited thereto as long as it is a speed that may be a reference for whether to apply compensation according to low temperature. Further, the condition determinator **210** may calculate and obtain it from the rack position information or the rotation amount information about the motor. The rack speed information may be information calculated from information measured in a tiny operation area to minimize the influence on other parts. In other words, if the absolute value of the rack speed information exceeds the preset reference speed according to the third compensation condition, the condition determinator **210** may withhold the application of compensation for friction. In contrast, if the absolute value of the rack speed information is less than or equal to the preset reference speed, the condition determinator **210** may determine that the third compensation condition is met and may thus determine to apply compensation for friction at low temperature.

As an example, if all of the first compensation condition, the second compensation condition, and the third compensation condition are met, the condition determinator **210** of the steering control device **200** may determine to apply compensation for friction according to low temperature (S**430**). For example, the condition determinator **210** generates enable flag **1** for applying a compensation logic if the PCB temperature information, rack position information, and rack speed information meet all of the preset compensation conditions. Here, the compensation logic may be a logic for determining a friction level based on a recursive-least-squares algorithm and compensating for rack force information estimated according to the friction level.

FIG. **5** is a view illustrating a level determinator and a controller of a steering control device according to an embodiment of the disclosure.

Referring to FIG. **5**, an operation in which the level determinator **220** and the controller **230** of the steering control device **200** according to an embodiment of the disclosure determine a friction level and compensate for rack force information estimated according to the friction level may be described. For example, if all of the compensation conditions are met so that it is determined to apply compensation, the level determinator **220** of the steering control device **200** determines to apply compensation, the level determinator **220** may determine the friction level based on the rack force information. For example, if enable flag **1** is input, the level determinator **220** may determine the friction level using the recursive-least-squares algorithm **510**. Further, the level determinator **220** may estimate a parameter of a system approximated by the recursive-least-squares algorithm **510** using the rack force information as an input. Here, the estimated parameter is parameter b corresponding to the friction level and may be a coefficient of a polynomial. In other words, the level determinator **220** may determine that the parameter b estimated in the recursive-least-squares algorithm **510** is the friction level.

Specifically, the recursive-least-squares algorithm **510** may be an adaptive filter algorithm that recursively finds the coefficient for minimizing the weighted linear least square cost function related to the input. The approximated system may be defined as:

$z=Ax+b\ \mathrm{sign}(y)$ [Equation 1]

Here, x may be the rack position information, y may be the rack speed information, and z may be the rack force information. However, Equation 1 describes an example of the approximated system, and is not limited thereto.

Also, the recursive-least-squares algorithm may define a cost function as the sum of values obtained by multiplying an error by a weighting factor to estimate the parameter, and update the coefficient to minimize the sum. In this case, the error may be a difference between an actual value of the rack force information and an estimated value. The weighting factor is a forgetting factor, and may decrease the weight of the error in the previous nth step to increase the weight of the value that came in the last step.

The forgetting factor applied to the recursive-least-squares algorithm is a value that determines the estimated rate of change, and as it gets closer to 1, the rate of change may decrease. Further, the forgetting factor may require an appropriate value between 0 and 1 along with the initial values of the estimate and covariance for reasonable estimation. Accordingly, the level determinator **220** may compare the input rack force information calculated using the recursive-least-squares algorithm with the output rack force information calculated with the estimated parameter, and determine the estimated parameter as the friction level.

Also, as an example, the controller **230** of the steering control device **200** may compensate for the rack force information based on the determined friction level and convert the rack force information into final rack force information. For example, the controller **230** may determine whether to compensate for the rack force information using the friction level comparator **520**. The friction level comparator **520** may be operated if an enable flag **2** is input as it corresponds to a low-temperature state. Accordingly, in the low-temperature state, the controller **230** may compare the determined friction level with a preset reference friction level and determine to compensate for the rack force information only if the friction level is greater than or equal to the reference friction level. Further, the reference friction level may be calculated from rack force information estimated during a time corresponding to a compliance zone in the room-temperature state. This may be because the friction level increases as the friction level changes from the room-temperature state to the low-temperature state.

Here, the rack force information is estimated based on the sensing information, and may mean the sum of the friction of the steering gear, the suspension friction of the host vehicle, and the reaction force of the tire. Specifically, the rack force information may be estimated by calculating rack speed information and rack acceleration information by performing first-order differentiation and second-order differentiation on the measured rack position information, and reflecting mass of the rack, damping of the rack, and stiffness of the rack. Further, the compliance zone may refer to a range in which the rack does not move even if the steering gear is driven. Specifically, the compliance zone may be set to a range in which the reaction force motor is rotated such that the rack does not move although the rack moves as the reaction force motor controlled by the command signal rotates.

As a specific example, the controller **230** may store the friction level calculated by operating a preset profile at room temperature in a non-volatile memory (NVM) area and use the friction level as a reference friction level. The controller **230** may determine whether to apply the friction compensator **530** based on the stored reference friction level. In other words, the controller **230** may compare the determined friction level with a preset reference friction level to apply the friction compensator **530** to compensate for the rack force information only when the friction level is equal to or greater than the reference friction level.

As another example, the controller **230** may input the estimated rack force information to the friction compensator **530** to convert the estimated rack force information into final rack force information. The controller **230** may compensate for the estimated rack force information to reduce the increased friction as it becomes a low temperature state and convert the rack force information into final rack force information. Details of the friction compensator **530** are described below with reference to FIG. **6**.

FIG. **6** is a view illustrating an operation for changing into final rack force information by a controller of a steering control device according to an embodiment of the disclosure.

Referring to (a) and (b) of FIG. **6**, an operation in which the controller **230** of the steering control device **200** according to an embodiment of the disclosure compensates for the rack force information **610** estimated using the dead zone and converts the rack force information **610** into final rack force information **620** may be described. For example, the controller **230** of the steering control device **200** may determine the final rack force information **620** to reduce the increased friction in the low-temperature state by applying the friction compensator **530** to the estimated rack force information **610**. In this case, the friction compensator **530** may be set to include a dead zone **630**. For example, the controller **230** may set the dead zone **630** to an arbitrary range based on the estimated rack force information **610**, and may lower the estimated rack force information **610** using the dead zone to convert the rack force information **610** into the final rack force information **620**. (a) of FIG. **6** illustrates rack force information **610** estimated before compensation and final rack force information **620** converted after compensation.

Specifically, the controller **230** may set the dead zone **630** to an arbitrary range based on the rack force information, and may convert the estimated rack force information to 0 in a range included in the dead zone **630**. In contrast, in other ranges not included in the dead zone **630**, the controller **230** may convert the estimated rack force information by increasing the estimated rack force information by a predetermined size. Referring to FIG. **6**(*b*), the controller **230** may set a range in which the rack force information is greater than or equal to a and less than b as the dead zone **630**. Further, the controller **230** may convert the final rack force information to 0 in the range set to the dead zone **630**. In contrast, in the range where the rack force information is less than a, the controller **230** may convert the final rack force information to a value obtained by reducing the estimated rack force information by a. In the range where the rack force information is b or more, the controller **230** may convert the final rack force information to a value obtained by reducing the estimated rack force information by b. In general, a may be −b.

FIG. **7** is a view illustrating an operation for changing into final rack force information by a controller of a steering control device according to an embodiment of the disclosure.

Referring to (a) and (b) of FIG. **7**, an operation in which the controller **230** of the steering control device **200** according to an embodiment of the disclosure compensates for the rack force information **610** estimated using the back lash and converts the rack force information **610** into final rack force

information **710** may be described. For example, the controller **230** of the steering control device **200** may determine the final rack force information **710** to reduce the increased friction in the low-temperature state by applying the friction compensator **530** to the estimated rack force information **610**. In this case, the friction compensator **530** may be set to include the back lash. For example, the controller **230** may apply a back lash effect to each range based on the estimated rack force information **610**, thereby decreasing the estimated rack force information **610** and converting it into the final rack force information **710**. (a) of FIG. **7** illustrates rack force information **610** estimated before compensation and final rack force information **710** converted after compensation.

Specifically, the controller **230** may output w(t) as the final rack force information **710** by applying the back lash to the rack force information **610** that is A sin (wt). w(t) may be expressed as in Equation 2.

$$w(t) = (A - b)k \quad \text{[Equation 2]}$$

$$\frac{\pi}{2} < \text{wt} \leq \pi - \gamma$$

$$w(t) = (\text{Asin}(\text{wt}) - b)k$$

$$\pi - \gamma < \text{wt} \leq \frac{3\pi}{3}$$

$$w(t) = -(A - b)k$$

$$\frac{3\pi}{2} < \text{wt} \leq 2\pi - \gamma$$

$$w(t) = (\text{Asin}(\text{wt}) - b)k$$

$$2\pi - \gamma < \text{wt} \leq \frac{5\pi}{2}$$

$$\text{where } \gamma = \sin^{-1}\left(1 - \frac{2b}{A}\right)$$

Here, b may be the size of back lash. Referring to (b) of FIG. **7**, the controller **230** may convert into the final rack force information **710** as a value proportional to the value obtained by reducing the amplitude of the estimated rack force information **610** by the back lash size in an arbitrary range. The controller **230** may convert the final rack force information to a value proportional to the value obtained by decreasing the estimated rack force information **610** by b in any other ranges.

A steering control method that may be performed by the steering control device **200** described above in connection with FIGS. **1** to **7** is described below.

FIG. **8** is a flowchart illustrating a steering control method according to an embodiment of the disclosure.

Referring to FIG. **8**, a steering control method according to an embodiment of the disclosure may include a condition determination step (S**810**). As an example, the steering control device may determine whether to apply compensation for friction occurring in the mechanism of the road wheel actuator (RWA) in the low-temperature state. For example, the steering control device may determine whether to apply compensation for friction occurring in the mechanism of the road wheel actuator in the low-temperature state based on the PCB temperature information, the rack position information, and the rack speed information according to a predetermined compensation condition. Specifically, the steering control device may sequentially determine a first compensation condition, a second compensation condition, and a third compensation condition included in the compensation condition. If all of the first compensation condition, the second compensation condition, and the third compensation condition are met, the steering control device may determine to apply compensation for friction. Here, it may be determined that the first compensation condition is that the PCB temperature information is less than or equal to a preset reference temperature. The second compensation condition may be determined when the first compensation condition is met, and it may be determined that the second compensation condition is that the absolute value of the rack position information is less than or equal to a preset reference position. The third compensation condition may be determined when the first compensation condition and the second compensation condition are met, and it may be determined that the third compensation condition is that the absolute value of the rack speed information is less than or equal to a preset reference speed.

The steering control method according to an embodiment may include a level determination step (S**820**). As an example, the steering control device may determine the friction level based on rack force information depending on the result of determination of whether to apply compensation. For example, when it is determined to apply compensation for friction, the steering control device may determine the friction level based on the rack force information. Specifically, the steering control device may estimate a parameter through a recursive-least-squares algorithm using rack force information as an input and determine the estimated parameter as a friction level. The steering control device may compare the input rack force information calculated by the recursive-least-squares algorithm with the output rack force information calculated with the estimated parameter. In this case, the estimated parameter b may be determined as the friction level. In other words, the steering control device may determine the friction level by estimating a parameter that is a specific coefficient of the polynomial based on the recursive-least-squares algorithm using the rack force information as an input.

The steering control method according to an embodiment may include a control step (S**830**). As an example, the steering control device may control the steering feedback actuator (SFA) based on the final rack force information where the compensation for friction has been applied according to the low temperature. For example, the steering control device may compensate for the rack force information based on the determined friction level and convert the rack force information into final rack force information. The steering control device may control the steering feedback actuator (SFA) based on the final rack force information. Specifically, the steering control device may compare the friction level with a preset reference friction level to compensate for the rack force information only when the friction level is equal to or greater than the reference friction level. Here, the reference friction level may be calculated from rack force information estimated during a time corresponding to a compliance zone in the room-temperature state. Specifically, the steering control device may set an arbitrary section as the dead zone based on the estimated rack force information, and convert into the final rack force information by lowering the estimated rack force information using the dead zone. Specifically, the compliance zone may be set to a range in which the reaction force motor is rotated such that the rack does not move although the rack moves as the reaction force motor controlled by the command signal rotates.

As described above, according to the disclosure, there may be provided a steering control device and method

capable of compensating for the effect on the increased friction level of the road wheel actuator (RWA) mechanism at a low temperature in a steer by wire (SBW) system. In particular, there may be provided a steering control device and method capable for compensating for heavy steering that the driver may feel at low temperature by determining a friction level at a low temperature while driving according to a preset compensation condition and compensating for rack force information with respect to the friction level.

The above description has been presented to enable any person skilled in the art to make and use the technical idea of the disclosure, and has been provided in the context of a particular application and its requirements. Various modifications, additions and substitutions to the described embodiments will be readily apparent to those skilled in the art, and the general principles defined herein may be applied to other embodiments and applications without departing from the spirit and scope of the disclosure. The above description and the accompanying drawings provide an example of the technical idea of the disclosure for illustrative purposes only. That is, the disclosed embodiments are intended to illustrate the scope of the technical idea of the disclosure. Thus, the scope of the disclosure is not limited to the embodiments shown, but is to be accorded the widest scope consistent with the claims. The scope of protection of the disclosure should be construed based on the following claims, and all technical ideas within the scope of equivalents thereof should be construed as being included within the scope of the disclosure.

What is claimed:

1. A steering control device applied to a steer by wire (SBW) system of a vehicle, the steering control device comprising:

a condition determinator configured to determine whether to apply compensation for friction generated in a mechanism of a road wheel actuator (RWA) in a low-temperature state based on printed circuit board (PCB) temperature information, rack position information, and rack speed information according to a preset compensation condition;

a level determinator configured to determine a friction level based on the rack force information according to a result of the determination by the condition determinator; and

a controller configured to convert the rack force information into final rack force information by compensating for the rack force information based on the determined friction level and control a steering feedback actuator (SFA) based on the final rack force information.

2. The steering control device of claim **1**, wherein the condition determinator sequentially determines a first compensation condition, a second compensation condition, and a third compensation condition included in the compensation condition and,

if all of the first compensation condition, the second compensation condition, and the third compensation condition are met, determines to apply the compensation for the friction.

3. The steering control device of claim **2**, wherein the first compensation condition is that the PCB temperature information is a preset reference temperature or less.

4. The steering control device of claim **2**, wherein the second compensation condition is determined when the first compensation condition is met and is that an absolute value of the rack position information is a preset reference position or less.

5. The steering control device of claim **2**, wherein the third compensation condition is determined when the first compensation condition and the second compensation condition are met and is that an absolute value of the rack speed information is a preset reference speed or less.

6. The steering control device of claim **1**, wherein the level determinator estimates a parameter through a recursive-least-squares algorithm using the rack force information as an input and determines that the parameter is the friction level.

7. The steering control device of claim **1**, wherein the controller compares the friction level with a preset reference friction level to compensate for the rack force information only when the friction level is the reference friction level or more.

8. The steering control device of claim **7**, wherein the reference friction level is calculated from rack force information estimated during a time corresponding to a compliance zone in a room-temperature state.

9. The steering control device of claim **7**, wherein the controller converts the rack force information into the final rack force information by compensating for rack force information estimated to reduce friction increased according to the low-temperature state.

10. The steering control device of claim **9**, wherein the controller configures a friction compensator including at least one of a dead zone and a back lash based on the estimated rack force information and applies the friction compensator to convert the rack force information into the final rack force information.

11. A steering control method applied to a steer by wire (SBW) system of a vehicle, the steering control method comprising:

determining whether to apply compensation for friction generated in a mechanism of a road wheel actuator (RWA) in a low-temperature state based on PCB temperature information, rack position information, and rack speed information according to a preset compensation condition;

determining a friction level based on the rack force information according to a result of the determination of whether to apply the compensation; and

converting the rack force information into final rack force information by compensating for the rack force information based on the determined friction level and controlling a steering feedback actuator (SFA) based on the final rack force information.

12. The steering control method of claim **11**, wherein the determining whether to apply compensation sequentially determines a first compensation condition, a second compensation condition, and a third compensation condition included in the compensation condition and,

if all of the first compensation condition, the second compensation condition, and the third compensation condition are met, determines to apply the compensation for the friction.

13. The steering control method of claim **12**, wherein the first compensation condition is that the PCB temperature information is a preset reference temperature or less.

14. The steering control method of claim **12**, wherein the second compensation condition is determined when the first compensation condition is met and is that an absolute value of the rack position information is a preset reference position or less.

15. The steering control method of claim **12**, wherein the third compensation condition is determined when the first compensation condition and the second compensation con-

dition are met and is that an absolute value of the rack speed information is a preset reference speed or less.

16. The steering control method of claim **11**, wherein the determining the friction level estimates a parameter through a recursive-least-squares algorithm using the rack force information as an input and determines that the parameter is the friction level.

17. The steering control method of claim **11**, wherein the controlling the SFA compares the friction level with a preset reference friction level to compensate for the rack force information only when the friction level is the reference friction level or more.

18. The steering control method of claim **17**, wherein the reference friction level is calculated from rack force information estimated during a time corresponding to a compliance zone in a room-temperature state.

19. The steering control method of claim **17**, wherein the controlling the SFA converts the rack force information into the final rack force information by compensating for rack force information estimated to reduce friction increased according to the low-temperature state.

20. The steering control method of claim **19**, wherein the controlling the SFA configures a friction compensator including at least one of a dead zone and a back lash based on the estimated rack force information and applies the friction compensator to convert the rack force information into the final rack force information.

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