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Steer-by-wire control device and steer-by-wire control method

Abstract

A steer-by-wire control device according to the present invention includes a control device that controls a first motor that operates a steering wheel of a vehicle and a second motor that controls steering operation of a wheel. Before making a transition to an automatic driving mode of the vehicle, the control device applies input torque to the steering wheel by the first motor in a forward rotation direction and a backward rotation direction of rotation directions of the first motor, acquires behavior information of the steering wheel obtained by application of the input torque, and determines whether or not to estimate a control parameter of the steering wheel based on the behavior information. The behavior information includes at least one of a value of a rotation angle of a steering wheel and a value obtained by time-differentiating a rotation angle.

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Background/Summary

TECHNICAL FIELD

(1) The present invention relates to a steer-by-wire control device that is a steering control device mounted on an automobile.

BACKGROUND ART

(2) In a steering control device for an automobile (hereinafter, referred to as a “vehicle”), a steering control device of what is called a steer-by-wire system in which a steering shaft connected to a steering wheel is mechanically separated from a steering mechanism is known. A steer-by-wire control device, which is a steering control device of a steer-by-wire system, detects a rotation angle, a rotation direction, and the like of a steering shaft, and, based on detection signals of these, controls an operation amount of a steering electric actuator to drive a steering axle.

(3) In the steer-by-wire system, since a correspondence relationship between an operation amount of a steering wheel and a steering amount of a steering electric actuator can be set without being mechanically restricted, a steer-by-wire control device can flexibly cope with a change in a steering characteristic according to a traveling state of a vehicle such as a level of a speed of the vehicle, a length of a turning radius, presence or absence of acceleration or deceleration of the vehicle, and has an advantage that the degree of freedom in design is improved. Furthermore, the steer-by-wire control device has many advantages as compared with a conventional steering control device, such as an advantage of being easily developed into an automatic steering system including lane keeping control.

(4) A reaction force electric actuator for applying a steering reaction force torque to a steering wheel is attached to a steering shaft separated from a steering mechanism. As an appropriate steering reaction force torque is applied to a steering wheel, a driver of a vehicle can perform steering operation with a sense as if the steering wheel and a steering mechanism are mechanically connected.

(5) In a vehicle including this type of steering control device, it is assumed that the steering control device switches between an automatic steering mode (hereinafter, also referred to as “active steering mode” or “automatic driving mode”) and a manual steering mode (hereinafter, also referred to as “manual steering mode” or “manual driving mode”) during driving. Then, in general, for example, a steering control device is configured to execute the manual steering mode in a case where a driver grips a steering wheel, and execute the active steering mode in a case where the driver does not grip the steering wheel.

(6) In a case where the active steering mode is executed, a steering control device obtains a steering angle of a steered wheel based on an external steering command value from an automatic steering system, and controls a steering electric actuator so as to have the obtained steering angle to drive the steered wheel. In this case, a steering wheel is rotated corresponding to the steering angle of the steered wheel by a reaction force electric actuator, and a rotation angle of the steering wheel and the steering angle of the steered wheel are matched with each other.

(7) Note that examples of automatic steering control of an automatic steering system include lane keeping control for traveling so as not to deviate from a white line laid on a road, automatic driving control for traveling along a traveling route, and the like. In a case of determining that continuation of automatic steering control is difficult during execution of the automatic steering control, an automatic steering system can transfer driving authority to a driver. Further, even when a driver steers a steering wheel to cancel automatic steering control with some intention while the active steering mode is executed, the system needs to promptly detect this and transfer driving authority

to the driver.
(8) In these cases, the automatic steering system needs to transfer driving authority to a driver after confirming that the driver grips or steers a steering wheel. For this reason, in a steering control device, detecting that a driver grips a steering wheel (grip detection) and detecting that the driver steers the steering wheel (steering detection) are important problems.
(9) With regard to the grip detection and the steering detection described above, there is known a method of estimating torque (hereinafter, referred to as "driver torque") applied by a driver and detecting gripping and steering of a driver based on a value of the estimated driver torque. The moment of inertia of a steering wheel is used to estimate the driver torque. The moment of inertia of a steering wheel is an important parameter directly linked to estimation accuracy of the driver torque, and is a control parameter that affects behavior of the steering wheel. Such control parameters of a steering wheel include a friction torque, a gravitational torque, and the like in addition to the moment of inertia.
(10) Such a problem of estimating the moment of inertia of a load attached to an actuator is a general problem without limitation to a steer-by-wire control device. A conventional technique for estimating the moment of inertia of a load attached to an actuator is described in PTL 1, for example. In the technique described in PTL 1, in a power assist type mobile body that moves by a force of a motor and a force of a person, the moment of inertia of a load (mobile body such as a carriage) attached to the motor is estimated by estimation of the equivalent moment of inertia of a mobile body using an acceleration of the mobile body detected by an acceleration detection unit and armature current of the motor detected by a current sensor.
CITATION LIST
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SUMMARY OF INVENTION
Technical Problem
(12) The technique described in PTL 1 cannot take into consideration that a driver grips a steering wheel, and when the technique described in PTL 1 is used for a steering control device, there is a concern that the moment of inertia of a steering wheel cannot be accurately estimated in a case where a driver grips the steering wheel.
(13) Further, when the moment of inertia of a steering wheel is estimated, the steering wheel needs to be operated by torque of a motor. At this time, when the steering wheel greatly operates independently of a driver's intention, there is a concern that the driver feels uneasy or uncomfortable.
(14) For this reason, a steer-by-wire control device and a control method for a steer-by-wire system (steer-by-wire control method) capable of accurately estimating a control parameter of a steering wheel such as the moment of inertia by a method that hardly gives uneasiness or discomfort to a driver of a vehicle are desired.
(15) An object of the present invention is to provide a steer-by-wire control device and a steer-by-wire control method capable of accurately estimating a control parameter of a steering wheel by a method that hardly gives uneasiness or discomfort to a driver of a vehicle.
Solution to Problem
(16) A steer-by-wire control device according to the present invention includes a first motor that operates a steering wheel of a vehicle, a second motor that controls steering operation of a wheel of the vehicle, and a control device that controls the first motor and the second motor. Before the vehicle makes a transition to an automatic driving mode, the control device applies predetermined input torque to the steering wheel by the first motor in both a forward rotation direction and a backward rotation direction of rotation directions of the first motor. The control device acquires behavior information that is information about behavior of the steering wheel obtained by application of the input torque. The control device determines whether or not to make a transition

to a control parameter estimation mode for estimating a control parameter of the steering wheel based on the behavior information. The behavior information includes at least one of a value of a rotation angle of the steering wheel and a value obtained by time-differentiating the rotation angle.
(17) A steer-by-wire control method according to the present invention is executed by a control device that controls a first motor that operates a steering wheel of a vehicle and a second motor that controls steering operation of a wheel of the vehicle. The steer-by-wire control method includes the steps of applying predetermined input torque to the steering wheel by the first motor in both a forward rotation direction and a backward rotation direction of rotation directions of the first motor before the vehicle makes a transition to an automatic driving mode, acquiring behavior information that is information about behavior of the steering wheel obtained by application of the input torque, and determining whether or not to make a transition to a control parameter estimation mode for estimating a control parameter of the steering wheel based on the behavior information. The behavior information includes at least one of a value of a rotation angle of the steering wheel and a value obtained by time-differentiating the rotation angle.
Advantageous Effects of Invention
(18) According to the present invention, it is possible to provide a steer-by-wire control device and a steer-by-wire control method capable of accurately estimating a control parameter of a steering wheel by a method that hardly gives uneasiness or discomfort to a driver of a vehicle.

Description

BRIEF DESCRIPTION OF DRAWINGS
(1) FIG. **1** is a diagram illustrating a configuration of a steer-by-wire control device according to a first embodiment of the present invention.
(2) FIG. **2** is a diagram illustrating a cross section along an axial direction of a steering mechanism.
(3) FIG. **3** is a diagram illustrating an outline of a configuration in which a control device controls a reaction force motor and a steering motor.
(4) FIG. **4** is a diagram illustrating balance of torque around a steering wheel in the first embodiment.
(5) FIG. **5** is a diagram illustrating a flowchart of processing in which the control device detects a change in the moment of inertia of the steering wheel.
(6) FIG. **6**A is a diagram illustrating an example of a waveform of a reference torque (input torque).
(7) FIG. **6**B is a diagram illustrating an example of a rotation angle of the steering wheel obtained by application of the reference torque illustrated in FIG. **6**A.
(8) FIG. **6**C is a diagram illustrating an example of an angular velocity of the steering wheel obtained by application of the reference torque illustrated in FIG. **6**A.
(9) FIG. **7**A is a diagram illustrating an example of a waveform of a reference torque (input torque) in a control parameter estimation mode.
(10) FIG. **7**B is a diagram illustrating an example of angular acceleration of the steering wheel obtained by application of the reference torque illustrated in FIG. **7**A.
(11) FIG. **8**A is a diagram illustrating balance of torque around the steering wheel in a second embodiment.
(12) FIG. **8**B is a diagram for explaining gravitational torque.
DESCRIPTION OF EMBODIMENTS
(13) A steer-by-wire control device according to the present invention is a steering control device mounted on a vehicle, and includes, for example, a configuration described in the claims. A steer-by-wire control method according to the present invention is executed by a steering control device mounted on a vehicle, and includes, for example, a configuration described in the claims.
(14) For example, the steer-by-wire control device according to the present invention applies

predetermined input torque to a steering wheel by a first motor (for example, a reaction force electric motor) that operates the steering wheel in both a forward rotation direction and a backward rotation direction of rotation directions of the first motor before a vehicle makes a transition to the automatic driving mode, acquires behavior information of the steering wheel obtained by the application, and determines whether or not to estimate a control parameter (for example, the moment of inertia) of the steering wheel on the basis of the behavior information.
(15) By making such a determination based on the behavior information of the steering wheel, the moment of inertia of the steering wheel can be estimated in a state where a driver of the vehicle releases his/her hands from the steering wheel, that is, in a state where the driver torque is zero, and the moment of inertia can be accurately estimated.
(16) Further, as input torque is applied to the steering wheel in both the forward rotation direction and the backward rotation direction of the rotation directions of the first motor, it is possible to generate the same degree of change in acceleration by smaller rotation operation of the steering wheel as compared with a case where input torque is applied only in one direction, and it is possible to accurately detect a change in the moment of inertia while reducing discomfort of the driver. Furthermore, as input torque is applied in both the forward rotation direction and the backward rotation direction in the rotation direction of the first motor, the steering wheel can be returned to a neutral point after rotation operation, and it is possible to prevent the driver from feeling uneasy due to a position of the steering wheel deviating from the neutral point.
(17) The steer-by-wire control device and the steer-by-wire control method according to the present invention can accurately estimate a control parameter of a steering wheel by a method that hardly gives uneasiness and discomfort to a driver of a vehicle by the above control, and can realize the grip detection and the steering detection of the steering wheel with high accuracy.
(18) Hereinafter, the steer-by-wire control device and the steer-by-wire control method according to an embodiment of the present invention will be described in detail with reference to the drawings.
(19) In an embodiment below, the moment of inertia will be mainly described as a control parameter that affects behavior of a steering wheel. Control parameters of a steering wheel include a friction torque and a gravitational torque, and the friction torque and the gravitational torque will be described in a second embodiment.
(20) Note that the present invention is not limited to an embodiment below, and various variations and applications within a technical concept of the present invention are also included in the scope of the present invention.
First Embodiment
(21) Before description of a specific embodiment of the present invention, a general configuration of the steer-by-wire control device will be described with reference to FIGS. **1** and **2**. In the steer-by-wire control device described below, with respect to a configuration in which a steering shaft is separated from a steering axle, a rotation angle of the steering shaft, a disturbance torque, a steering angle of a steered wheel, and the like are detected by sensors (for example, a rotation angle sensor, a current sensor, and a rack position sensor), and operation amounts of a steering electric actuator and a reaction force electric actuator are controlled based on a detection signal of the sensors.
(22) FIG. **1** is a diagram illustrating a configuration of the steer-by-wire control device according to a first embodiment of the present invention. The steer-by-wire control device according to the present embodiment includes a control device **19**, a reaction force electric motor **18**, and a steering electric motor provided in a steering electric motor mechanism **21**.
(23) A steered wheel **10** is configured to be steered by a tie rod **11**. The tie rod **11** is connected to a steering axle **17** (also referred to as a rack bar) of a steering mechanism **16**. The steering mechanism **16** includes the steering axle **17** and the steering electric motor mechanism **21**.
(24) A steering wheel **12** is connected to a steering shaft **13**. The steering shaft **13** can be provided with a sensor such as a steering operation angle sensor as necessary.
(25) The steering shaft **13** is not connected to the steering axle **17**, and includes the reaction force

electric motor **18** at a tip of the steering shaft **13**. That is, the steering shaft **13** has a configuration not mechanically connected to the steering mechanism **16**, and as a result, the steering shaft **13** and the steering mechanism **16** are separated from each other.

(26) The reaction force electric motor **18** is a reaction force electric actuator that is controlled by the control device **19**, applies steering reaction force torque to the steering shaft **13**, and operates the steering wheel **12**. Note that the reaction force electric actuator may be an electric actuator of a type other than an electric motor. Hereinafter, the reaction force electric motor **18** is referred to as the reaction force motor **18**.

(27) The reaction force motor **18** includes a rotation angle sensor **14** as a steering operation amount sensor that detects rotation of the steering shaft **13**. The rotation angle sensor **14** detects a rotation angle of the reaction force motor **18**, that is, a rotation angle of the steering wheel **12**. The steering operation amount sensor does not need to be the rotation angle sensor **14**, and may be an optional sensor capable of detecting rotation of the steering shaft **13**. For example, the steering operation amount sensor may be a steering operation angle sensor that detects a steering operation angle of the steering shaft **13**.

(28) Further, the reaction force motor **18** includes a current sensor **15** which is a steering operation amount sensor. The current sensor **15** detects current flowing through a coil of the reaction force motor **18**. This current can be used, for example, in a case of estimating a disturbance torque (for example, torque applied to the steering wheel **12** during traveling of a vehicle) or in a case of determining whether or not a driver of a vehicle grips the steering wheel **12**.

(29) The steering mechanism **16** including the steering axle **17** is provided with the steering electric motor mechanism **21**. The steering electric motor mechanism **21** controls steering operation of the steering axle **17**. Note that, in the present embodiment, the steering mechanism **16** includes the steering electric motor mechanism **21** since an electric motor (a steering electric motor **35** to be described later) is used as a steering electric actuator, but the steering electric actuator may be an electric actuator of a type other than an electric motor.

(30) The control device **19** controls the reaction force motor **18** and the steering electric motor mechanism **21** of the steering mechanism **16**. The control device **19** receives input of a signal regarding a rotation angle of the steering wheel **12** detected by the rotation angle sensor **14** and a signal regarding current flowing through a coil of the reaction force motor **18** detected by the current sensor **15**. Note that, in addition to these detection signals, the control device **19** receives input of various detection signals from an external sensor **20**.

(31) The control device **19** calculates a control amount of the steering electric motor mechanism **21** based on information on an input rotation angle and current, and controls the steering electric motor mechanism **21**. Note that the control amount of the steering electric motor mechanism **21** can also be obtained based on a parameter other than a rotation angle and current.

(32) Although described in detail later, the steering electric motor mechanism **21** rotates an output pulley of the steering mechanism **16** from an input pulley via a belt, and further causes the steering axle **17** to perform stroke operation in an axial direction by a steering nut to steer the steered wheel **10**.

(33) The control device **19** calculates a control amount of the reaction force motor **18** based on information on an input rotation angle and current, rack position information detected by a rack position sensor **22**, and the like, and controls the reaction force motor **18**. The rack position sensor **22** detects a movement amount of the steering axle **17** from a reference position (neutral position). The movement amount of the steering axle **17** is information equivalent to a steering angle (steering amount) of the steered wheel **10**. Note that a control amount of the reaction force motor **18** can also be obtained based on a parameter other than information on a rotation angle and current, and a rack position information.

(34) Although illustrated as one functional block in FIG. **1**, the control device **19** includes a reaction force actuator control device and a steering actuator control device. The reaction force

actuator control device and the steering actuator control device are connected to each other by a communication line. The reaction force actuator control device is provided in the reaction force motor **18** and controls a reaction force electric actuator (the reaction force motor **18**). The steering actuator control device is provided in the steering electric motor mechanism **21** and controls a steering electric actuator (the steering electric motor **35** to be described later). Note that the reaction force actuator control device and the steering actuator control device can be configured by one of the control device **19**, and the reaction force electric actuator and the steering electric actuator can be controlled by one of the control device **19**.
(35) The steering mechanism **16** includes the rack position sensor **22** as a steering amount sensor that detects a steering amount of the steered wheel **10**. The rack position sensor **22** detects a stroke amount in the axial direction of the steering axle **17**, and detects and outputs an actual steering amount (steering angle) of the steered wheel **10**. The steering amount sensor does not need to be the rack position sensor **22**, but may be an optional sensor capable of detecting a position (steering amount) of the steering axle **17**. For example, the steering amount sensor may be a rotation angle sensor provided in the steering electric motor mechanism **21** that applies a steering force to the steering axle **17**.
(36) Note that the steering mechanism **16** includes the steering axle **17**, the steering electric motor mechanism **21**, a speed reduction mechanism, and the like, but a mechanism that transmits a steering force from the steering electric motor mechanism **21** to the steered wheel **10** is not limited to these.
(37) FIG. **2** is a diagram illustrating a cross section along an axial direction of the steering mechanism **16**. A configuration of the steering mechanism **16** will be described with reference to FIG. **2**.
(38) Each constituent of the steering mechanism **16** is housed in a housing **32** except for the steering electric motor mechanism **21**. The housing **32** includes a steering axle accommodation portion **30** that houses the steering axle **17** so as to be movable in the axial direction, and a speed reducer accommodation portion **31** that is arranged in an intermediate portion in the axial direction of the steering axle accommodation portion **30** and is formed to surround the steering axle **17**. A speed reduction mechanism **33** is housed in the speed reducer accommodation portion **31**.
(39) The steering electric motor mechanism **21** includes the steering electric motor **35**, a steering actuator control device **44** that controls the steering electric motor **35**, and a screw mechanism **36** that transmits output of the steering electric motor **35** to the steering axle **17**. The steering electric motor **35** is controlled by the control device **19** and controls steering operation of the steered wheel **10** of a vehicle. The steering actuator control device **44** controls a rotation amount, a rotation speed, and the like of the steering electric motor **35** according to a steering operation amount applied to the steering wheel **12** by a driver. Hereinafter, the steering electric motor **35** is referred to as the steering motor **35**.
(40) The screw mechanism **36** includes a steering nut **37** and an output pulley **38**. The output pulley **38** is a cylindrical member, is fixed to the steering nut **37**, and rotates integrally with the steering nut **37**. A cylindrical input pulley **39** is fixed to a drive shaft of the steering motor **35**. The input pulley **39** rotates integrally with a drive shaft of the steering motor **35**. A belt **40** is wound between the output pulley **38** and the input pulley **39**. The speed reduction mechanism **33** includes the input pulley **39**, the output pulley **38**, and the belt **40**.
(41) The steering nut **37** has an annular shape surrounding the steering axle **17** and is provided to be rotatable with respect to the steering axle **17**. The steering nut **37** includes a spiral groove on its inner peripheral portion, and this groove constitutes a nut side ball screw groove. The steering axle **17** includes a spiral groove on its outer peripheral portion, and this groove constitutes steering axle side ball screw grooves **17***a* and **17***b*.
(42) In a state where the steering nut **37** is inserted into the steering axle **17**, the nut side ball screw groove and the steering axle side ball screw grooves **17***a* and **17***b* constitute a ball circulation

groove. The inside of the ball circulation groove is filled with a plurality of metal balls, and when the steering nut **37** rotates, the balls move inside the ball circulation groove, so that the steering axle **17** moves in the axial direction (longitudinal direction) with respect to the steering nut **37**, and the steering axle **17** performs stroke operation.
(43) The steering the above-described mechanism **16** has configuration, and the steering actuator control device **44** controls a rotation amount, a rotation direction, a rotation speed, and the like of the steering motor **35** to operate the steering axle **17** in accordance with steering operation of the steering wheel **12**, so that a vehicle is operated.
(44) Note that, although FIG. **2** illustrates the steering mechanism **16** mounted on a front wheel of a vehicle, the steering mechanism **16** can also be mounted on a rear wheel of a vehicle. Therefore, not only a front wheel but also a rear wheel of a vehicle can be steered by the steering motor **35**.
(45) FIG. **3** is a diagram illustrating an outline of a configuration in which the control device **19** illustrated in FIG. **1** controls the reaction force motor **18** and the steering motor **35**. As described above, the control device **19** includes a reaction force actuator control device provided in the reaction force motor **18** and the steering actuator control device **44**. For the control device **19** illustrated in FIG. **3**, both the reaction force actuator control device and the steering actuator control device **44** are illustrated.
(46) The reaction force motor **18** connected to the steering shaft **13** is provided with the rotation angle sensor **14** and the current sensor **15**. The reaction force motor **18** is mechanically connected to the steering wheel **12**. The rotation angle sensor **14** is a sensor that detects a rotation angle of the reaction force motor **18**, in other words, a rotation angle of the steering wheel **12**. The current sensor **15** is a sensor that detects current flowing through a coil of the reaction force motor **18**.
(47) The control device **19** can identify a state in which a driver grips the steering wheel **12** and a state in which the driver does not grip the steering wheel **12** from information on a rotation angle of the steering wheel **12** obtained by the rotation angle sensor **14** and information on torque of the reaction force motor **18**.
(48) Note that the control device **19** can also use information from the current sensor **15** to identify a state in which a driver grips the steering wheel **12** and a state in which the driver does not grip the steering wheel **12**. For example, the control device **19** can detect a vibration component of current and determine whether or not a driver grips the steering wheel **12** from a change in a peak of the vibration component. As described above, a sensor suitable for the system can be used as a sensor that identifies a state in which a driver grips the steering wheel **12** and a state in which the driver does not grip the steering wheel **12**.
(49) The reaction force motor **18** is an electric motor that applies a steering reaction force torque to the steering shaft **13**, and is controlled by the control device **19** via a motor driver **23**. The steering motor **35** is an electric motor that operates the steering axle **17**, and is controlled by the control device **19** via a motor driver **24**.
(50) The control device **19** receives input of information from the rack position sensor **22** and the rotation angle sensor **14**, and controls the reaction force motor **18** based on the input information, so as to apply a steering reaction force torque to the steering shaft **13** to rotate the steering wheel **12**. Further, the control device **19** drives the steering axle **17** mechanically connected to the steering motor **35** by controlling the steering motor **35** on the basis of information input from the rotation angle sensor **14** and the current sensor **15** and information on an external steering command value.
(51) The control device **19** receives input of information on a rotation angle of the reaction force motor **18** from the rotation angle sensor **14**, and receives input of information on current flowing through a coil of the reaction force motor **18** from the current sensor **15**. Furthermore, the control device **19** receives input of information on a travel state of a vehicle that affects steering from a travel state sensor such as a vehicle speed sensor **25** and a yaw rate sensor **26**. Further, the control device **19** receives input of information on a movement position of the steering axle **17** from the rack position sensor **22**. The control device **19** can derive a steering amount (steering angle) of the

steered wheel **10** from the movement position of the steering axle **17**.

(52) The rack position sensor **22** is attached to a portion of the housing **32** covering the steering axle **17** (See FIGS. **1** and **2**), and can detect a position of the steering axle **17**. The steering axle **17** is directly connected to the tie rod **11**. For this reason, the control device **19** can detect a steering angle of the steered wheel **10** based on position information of the rack position sensor **22**. As described above, the rack position sensor **22** functions as a detector that detects a steering angle of the steered wheel **10**.

(53) Further, the control device **19** receives input of an external steering command value from an automatic steering system **27** (for example, an advanced driver assistance system, ADAS) as an external steering control means. The external steering command value is a command value calculated and derived by the automatic steering system **27**, and is external steering command information. The external steering command value is a command value for causing the steering mechanism **16** to steer a steered wheel, for example, in a case where a vehicle deviates from a white line on a road by lane keeping control, a case of avoiding an obstacle, or the like.

(54) The steer-by-wire control device according to the present embodiment includes the above configuration, and the control device **19** estimates the driver torque in order to detect that a driver grips the steering wheel **12**. In order to estimate the driver torque, it is necessary to obtain an inertia torque of the steering wheel **12**, and in order to obtain the inertia torque, it is necessary to obtain the moment of inertia of the steering wheel **12**. Hereinafter, an example of a method in which the steer-by-wire control device according to the present embodiment estimates and obtains the moment of inertia of the steering wheel **12** will be described. As described above, the moment of inertia is a control parameter that affects behavior of a steering wheel.

(55) FIG. **4** is a diagram illustrating balance of torque around the steering wheel **12**. FIG. **4** illustrates driver torque Ts, motor torque Tm, and inertia torque Tj. The driver torque Ts is torque applied by a driver. The motor torque Tm is torque generated by the reaction force motor **18**. The inertia torque Tj is torque generated by the moment of inertia of the steering wheel **12** (that is, the moment of inertia of the steering wheel **12** and a portion that rotates in conjunction with the steering wheel **12**). When estimating the driver torque Ts, balance of torque illustrated in FIG. **4** is considered.

(56) Hereinafter, as an example, as illustrated in FIG. **4**, a case in which the driver torque Ts is applied clockwise as viewed from an upper direction of the paper surface, and the motor torque Tm is applied counterclockwise as viewed from the upper direction of the paper surface so as to oppose the driver torque Ts will be described.

(57) As illustrated in FIG. **4**, balance between the driver torque Ts, the motor torque Tm, and the inertial torque Tj is expressed by Equation (1).

(58) $Ts = Tn - Tj \quad (1)$

(59) The motor torque Tm can be obtained from information on current of the current sensor **15**. The inertial torque Tj can be obtained from information on a rotation angle of the rotation angle sensor **14**. Specifically, the motor torque Tm is obtained by multiplying a current value detected by the current sensor **15** by a torque constant of the reaction force motor **18**. The inertia torque Tj is obtained by time-differentiating a rotation angle detected by the rotation angle sensor **14** twice to obtain a rotation angular acceleration, and multiplying the rotation angular acceleration by the moment of inertia of the steering wheel **12**. The driver torque Ts can be estimated by substitution of the motor torque Tm and the inertial torque Tj thus obtained into Equation (1).

(60) When estimating the driver torque Ts, it is necessary to pay attention to a point below. For example, in a case where an accessory such as a cover is attached to the steering wheel **12** or in a case where the steering wheel **12** is replaced, a value of the actual moment of inertia of the steering wheel **12** is different from a value of the moment of inertia at a design value. For this reason, a value of the inertia torque Tj obtained from the moment of inertia at a design value may be

different from an actual value of the inertia torque Tj. In such a case, there is a concern that an estimation error of the driver torque Ts increases. For this reason, in order to accurately estimate the driver torque Ts, it is necessary to accurately estimate the actual moment of inertia of the steering wheel **12**.

(61) In the steer-by-wire control device according to the present embodiment, the control device **19** applies a reference torque to the steering wheel **12** by the reaction force motor **18**, and detects a change in the moment of inertia from behavior of the steering wheel **12** obtained with respect to the reference torque. The reference torque is a predetermined input torque, and changes according to a waveform determined optionally in advance. The reference torque can be optionally determined, and is preferably large enough to allow detection of a change in the moment of inertia of the steering wheel **12**.

(62) In order to detect a change in the moment of inertia from behavior of the steering wheel **12** obtained by application of the reference torque, it is necessary to create a state in which the motor torque Tm and the inertia torque Tj are balanced as shown in Equation (2).

(63) $Tm = Tj \quad (2)$

(64) Equation (2) indicates a state where the driver torque Ts is zero from Equation (1), that is, a state where a driver does not touch the steering wheel **12**. When a change in the moment of inertia is detected by application of the reference torque in the state shown in Equation (2), the moment of inertia can be prevented from changing due to influence of a driver. Therefore, the reference torque needs to be applied in a state where the driver torque Ts is zero.

(65) Further, it is necessary to estimate the moment of inertia of the steering wheel **12** always before a vehicle makes a transition to the automatic driving mode for automatic driving. When the driver torque Ts is estimated based on a value of the moment of inertia at a design value although a value of the actual moment of inertia is different from a value of the moment of inertia at a design value, the estimated driver torque Ts is different from an actual value and includes an error. Then, due to this error, when the automatic steering system **27** erroneously recognizes whether or not a driver grips the steering wheel **12**, a vehicle may fall into a dangerous state.

(66) In order to prevent this, in the steer-by-wire control device according to the present embodiment, the control device **19** executes processing illustrated in a flowchart of FIG. **5** in order to check whether or not there is a change in the moment of inertia of the steering wheel **12** before a vehicle makes a transition to the automatic driving mode.

(67) FIG. **5** is diagram illustrating a flowchart of processing in which the control device **19** detects a change in the moment of inertia of the steering wheel **12**. FIG. **5** illustrates, as an example, a flowchart of processing in which the control device **19** detects a change in the moment of inertia triggered by turning on of an activation switch (hereinafter, referred to as “IGN”) of a vehicle. Note that the control device **19** may use a thing other than turning on of the IGN as a trigger as long as the processing of detecting a change in the moment of inertia is performed before transition to the automatic driving mode. For example, unlocking of a vehicle or sensing approach of a driver to a vehicle can be used as a trigger.

(68) In S**10**, the control device **19** determines whether or not a signal indicating that the IGN is turned on is input. In a case where the IGN is turned on, processing of S**11** is executed.

(69) In S**11**, the control device **19** applies the reference torque (input torque) to the steering wheel **12** by the reaction force motor **18**. As described later, the control device **19** determines to which mode (S**19** to S**21**) a transition is to be made based on information about behavior of the steering wheel **12** obtained by application of the reference torque.

(70) In S**12**, the control device **19** acquires information (behavior information) about behavior of the steering wheel **12** obtained by application of the reference torque. The behavior information includes, for example, at least one of a value of a rotation angle of the steering wheel **12**, and a value of angular velocity, a value of angular acceleration, and a value of angular jerk of the steering

wheel **12** obtained by time-differentiating the rotation angle.

(71) In S**13**, the control device **19** stores the behavior information acquired in S**12**. Note that the control device **19** stores a design value or a measured value after manufacturing as an initial value of the behavior information.

(72) In S**14**, the control device **19** calculates and obtains a change amount of the behavior information. The control device **19** compares the behavior information (current behavior information) acquired in S**12** with the behavior information (previous behavior information) already stored in S**13** when the IGN is turned on last time, and calculates a change amount of the current behavior information from the previous behavior information.

(73) The control device **19** preferably handles a change amount in the behavior information as an absolute value so that both a case where a value of the behavior information increases and a case where a value of the behavior information decreases can be considered. This is because a change amount of the current behavior information n from the previous behavior information includes a positive value (in a case where a value of the behavior information increases) and a negative value (in a case where a value of the behavior information decreases). That is, when an absolute value of a change amount of the behavior information is set as a change amount of the behavior information and a change amount of the behavior information is compared with a threshold in processing described below, the control device **19** preferably compares the magnitude of an absolute value of the change amount of the behavior information with the threshold.

(74) In S**15**, the control device **19** compares the change amount in the behavior information obtained in step S**14** with a predetermined threshold A. The threshold A is a value for determining whether or not the moment of inertia changes. In a case where the change amount is equal to or less than the threshold A, the control device **19** determines that the moment of inertia does not change because the change amount of the moment of inertia is within a predetermined range, and executes processing of S**17**. In a case where the change amount is larger than the threshold A, the control device **19** executes processing of S**16**.

(75) In S**17**, the control device **19** determines whether or not there is a start request for automatic driving (request for switching to automatic driving mode, that is, automatic steering mode) from a driver. In a case where there is a start request for automatic driving from a driver, the control device **19** executes processing of S**19**.

(76) In S**19**, the control device **19** makes a transition to the automatic driving mode and causes a vehicle to make a transition to the automatic driving mode. In this case, the control device **19** estimates the driver torque Ts by using a value of the moment of inertia used last time.

(77) Step S**16** is processing in a case where a change amount in the behavior information is larger than the threshold A. In S**16**, the control device **19** compares the change amount in the behavior information obtained in step S**14** with a predetermined threshold B. The threshold B is a value larger than the threshold A, and is a value for determining whether or not a driver touches the steering wheel **12** (that is, whether or not Equation (2) is satisfied). In a case where the change amount is equal to or less than the threshold B, a driver does not touch the steering wheel **12** (that is, Equation (2) is satisfied and the driver torque Ts is zero), but the change amount in the moment of inertia exceeds a predetermined range. Therefore, the control device **19** determines that it is necessary to estimate the moment of inertia, and executes processing of S**20**. In a case where the change amount is larger than the threshold B, the control device **19** executes processing of S**18**.

(78) In S**20**, since the change amount in the behavior information is larger than the threshold A and equal to or less than the threshold B, the control device **19** determines that the moment of inertia changes and the driver torque Ts is zero, and makes a transition to a control parameter estimation mode in which a control parameter of a steering wheel is estimated. In the control parameter estimation mode, the control device **19** estimates the moment of inertia of the steering wheel **12** by a method to be described later.

(79) When or after making a transition to the control parameter estimation mode, the control device

19 can notify a driver of the transition to the control parameter estimation mode or instruct the driver to release his/her hands from the steering wheel **12** until the moment of inertia is obtained. The control device **19** can perform such notification and instruction by outputting at least one of video, a character, and voice.

(80) S**18** is processing in a case where the change amount in the behavior information is larger than the threshold A and the threshold B. In this case, the control device **19** determines that a driver touches the steering wheel **12** (that is, the driver torque Ts is not zero) or the behavior information is changed due to disturbance. In S**18**, the control device **19** determines whether or not there is a start request for automatic driving (request for switching to the automatic driving mode) from a driver. In a case where there is a start request for automatic driving from the driver, the control device **19** executes processing of S**21**.

(81) In S**21**, the control device **19** makes a transition to an automatic driving canceling mode, and cancels the start request for automatic driving from the driver. In this case, since the driver manually drives in the manual driving mode, the control device **19** does not need to estimate the moment of inertia.

(82) When or after making a transition to the automatic driving canceling mode, the control device **19** can notify a driver that automatic driving is not possible or instruct the driver to release his/her hands from the steering wheel **12**. The control device **19** can perform such notification and instruction by outputting at least one of video, a character, and voice.

(83) Further, the control device **19** may re-execute the processing from S**11** after executing the processing of S**21**.

(84) In a case where a change amount of the moment of inertia of the steering wheel **12** exceeds a predetermined range, a value of the moment of inertia is different from a value at a design value, and the driver torque Ts is zero by execution of the processing illustrated in the flowchart of FIG. **5**, the control device **19** estimates the moment of inertia by a method described later, so that the driver torque Ts can accurately be estimated. Further, in a case where a change in the moment of inertia cannot be accurately detected, for example, in a case where a driver touches the steering wheel **12**, the control device **19** cancels a start request for automatic driving from the driver, and can avoid a vehicle from falling into a dangerous state due to erroneous recognition that the driver grips the steering wheel **12**. For this reason, in the steer-by-wire control device according to the present embodiment, it is possible to safely make a transition to automatic driving when making a transition to automatic driving.

(85) FIGS. **6**A to **6**C are diagrams for explaining a method of calculating a change amount of information (behavior information) about the behavior of the steering wheel **12** obtained by application of the reference torque. The method of calculating a change amount of the behavior information in S**14** of FIG. **5** will be specifically described with reference to FIGS. **6**A to **6**C.

(86) FIG. **6**A illustrates an example of a waveform of the reference torque (input torque). FIG. **6**A illustrates, as an example, the reference torque having an impulse waveform. FIG. **6**B illustrates an example of a rotation angle of the steering wheel **12** obtained by application of the reference torque illustrated in FIG. **6**A. FIG. **6**C illustrates an example of an angular velocity of the steering wheel **12** obtained by application of the reference torque illustrated in FIG. **6**A. In FIG. **6**B, the previous behavior information (rotation angle) is indicated by a solid line, the current behavior information (rotation angle) is indicated by a dotted line, and an arrival angle change amount that is a difference between peak values (arrival angles) of the previous and current rotation angles is indicated as a change amount in the behavior information. In FIG. **6**C, the previous behavior information (angular velocity) is indicated by a solid line, the current behavior information (angular velocity) is indicated by a dotted line, and an arrival angular velocity change amount that is a difference between peak values (arrival angular velocities) of the previous and current angular velocities is indicated as a change amount in the behavior information.

(87) For example, in a case where the steering wheel **12** is replaced with the steering wheel **12**

having a smaller moment of inertia than that of when the behavior information is acquired last time, it is considered that an arrival angle and an arrival angular velocity increase in the current behavior information as illustrated in FIGS. **6**B and **6**C. In view of the above, when calculating a change amount in the behavior information in S**14** of FIG. **5**, the control device **19** calculates an arrival angle change amount and an arrival angular velocity change amount. Then, the control device **19** compares the calculated change amount with the threshold A in S**15**, and compares the calculated change amount with the threshold B in S**16**.
(88) The control device **19** applies the reference torque (input torque) having an impulse waveform in both the forward rotation direction and the backward rotation direction of the reaction force motor **18**. As illustrated in FIG. **6**A, the torque having an impulse waveform is torque represented by a rectangular waveform having a positive value and a negative value. When the reference torque is in the form of an impulse, there is an advantage that a position of the rotated steering wheel **12** can be returned to a neutral point by a torque of a positive value (a forward rotation direction of rotation directions of the reaction force motor **18**) and a torque of a negative value (a backward rotation direction of rotation directions of the reaction force motor **18**), and a torque that rapidly changes can be applied by a rectangular waveform.
(89) By applying torque that rapidly changes as the reference torque in both the forward rotation direction and the backward rotation direction of the rotation directions of the reaction force motor **18**, the control device **19** can generate a similar change in acceleration by a small rotation operation of the steering wheel **12** as compared with a case where torque is applied only in one direction. For this reason, the control device **19** can accurately detect a change in the moment of inertia while reducing driver's discomfort. Furthermore, the control device **19** can return the steering wheel **12** to a neutral point after rotation operation by applying the reference torque in the forward rotation direction and the backward rotation direction of the rotation directions of the reaction force motor **18**. For this reason, the control device **19** can prevent a driver from feeling uneasy due to deviation of a position of the steering wheel **12** from a neutral point.
(90) FIGS. **6**B and **6**C illustrate a rotation angle and an angular velocity as an example of the behavior information for detecting a change in the moment of inertia. As the behavior information, an angular acceleration obtained by time-differentiating an angular velocity or an angular jerk obtained by time-differentiating an angular acceleration may be used.
(91) FIGS. **7**A and **7**B are diagrams for explaining a method of estimating the moment of inertia of the steering wheel **12**. A method of estimating the moment of inertia of steering wheel **12** in the control parameter estimation mode in S**20** in FIG. **5** will specifically be described with reference to FIGS. **7**A and **7**B.
(92) In the control parameter estimation mode, the control device **19** estimates the moment of inertia of the steering wheel **12** by applying the reference torque (input torque) to the steering wheel **12** by the reaction force motor **18** and calculating and obtaining a change amount in the behavior information of the steering wheel **12**, similarly to the processing illustrated in S**11** to S**14** of FIG. **5**. The control device **19** stores the estimated moment of inertia.
(93) FIG. **7**A illustrates an example of a waveform of the reference torque (input torque) in the control parameter estimation mode. FIG. **7**A illustrates, as an example, the reference torque having a sinusoidal waveform. FIG. **7**B illustrates an example of an angular acceleration of the steering wheel **12** obtained by application of the reference torque illustrated in FIG. **7**A. In FIG. **7**B, the previous behavior information (angular acceleration) is indicated by a solid line, the current behavior information (angular acceleration) is indicated by a dotted line, and an amplitude change amount which is a difference between peak values of the previous and current angular accelerations is indicated as a change amount in the behavior information.
(94) First, the control device **19** applies the reference torque to the steering wheel **12** by the reaction force motor **18**. In the control parameter estimation mode, the control device **19** applies the reference torque having a sinusoidal waveform as illustrated in FIG. **7**A, for example. When a

waveform of the reference torque is sinusoidal, the steering wheel **12** can be smoothly rotated, and discomfort can be prevented from being given to a driver.

(95) In the control parameter estimation mode, the control device **19** preferably applies, to the steering wheel **12** by the reaction force motor **18**, the reference torque with which a value of the behavior information larger than a value of the behavior information of the steering wheel **12** obtained by application of the reference torque in S**11** of the processing of detecting a change in the moment of inertia of the steering wheel **12** (FIG. **5**) is obtained. When a larger value of the behavior information (for example, a greater change in angular acceleration) is obtained, the control device **19** can estimate the moment of inertia more accurately.

(96) For this reason, when applying the reference torque in the control parameter estimation mode, the control device **19** preferably notifies a driver that the steering wheel **12** operates, and then causes the steering wheel **12** to perform a larger operation than that of when the reference torque (the reference torque having an impulse waveform in the present embodiment) is applied in S**11** of FIG. **5**. For example, in the control parameter estimation mode, the control device **19** preferably applies the reference torque having a maximum value larger than that of the reference torque applied in S**11** of FIG. **5**.

(97) Next, the control device **19** acquires the behavior information (angular acceleration in the present embodiment) of the steering wheel **12** obtained by application of the reference torque. Then, the control device **19** obtains a change rate of an amplitude of the current behavior information (angular acceleration) from an amplitude of the previous behavior information (angular acceleration). The control device **19** can estimate the current moment of inertia by multiplying the previous moment of inertia by a reciprocal of the obtained change rate of an amplitude of the behavior information. The control device **19** stores the previous behavior information and the previous moment of inertia. Note that the control device **19** stores a design value or a measured value after manufacture as an initial value of the moment of inertia.

(98) For example, in a case where the steering wheel **12** is replaced with the steering wheel **12** having a smaller moment of inertia than that of when the moment of inertia is previously estimated, it is considered that an amplitude of the angular acceleration increases in the current behavior information as illustrated in FIG. **7**B. The inertia torque Tj is obtained by multiplying the angular acceleration by the moment of inertia, and when the driver torque Ts is zero, the inertia torque Tj is balanced with the reference torque (motor torque Tm). Therefore, the control device **19** finds that the moment of inertia is decreased by an amount of increase in an amplitude of the angular acceleration. Then, the control device **19** can estimate the moment of inertia (current moment of inertia) after replacement of the steering wheel **12** by multiplying a reciprocal of a change rate (increase rate in the above description) of the amplitude by the moment of inertia (previous moment of inertia) before replacement of the steering wheel **12**.

(99) Note that, in the method of estimating the moment of inertia of the steering wheel **12** in the control parameter estimation mode, a method similar to the processing illustrated in S**11** to S**14** in the processing of detecting a change in the moment of inertia of the steering wheel **12** illustrated in FIG. **5** (method of calculating and obtaining a change amount in the behavior information by application of the reference torque) is executed. For this reason, the control device **19** can simultaneously perform the processing of S**11** to S**14** in the processing illustrated in FIG. **5** and the processing of estimating the moment of inertia of the steering wheel **12** in the control parameter estimation mode. When these pieces of processes are performed at the same time, the control device **19** gives even less uneasiness or discomfort to a driver of a vehicle and can quickly estimate the moment of inertia.

(100) However, in order to estimate the moment of inertia more accurately, it is preferable to separately perform the processing from S**11** to S**14** in the processing illustrated in FIG. **5** and the processing of estimating the moment of inertia of the steering wheel **12** in the control parameter estimation mode, and to apply the reference torque suitable for each piece of the processing (for

example, to apply the reference torque of an impulse form and the reference torque of a sinusoidal form).
(101) In the steer-by-wire control device according to the present embodiment, as described above, the control device **19** can accurately estimate the moment of inertia of the steering wheel **12** by a method that hardly gives uneasiness or discomfort to a driver of a vehicle. For this reason, the steer-by-wire control device according to the present embodiment can accurately estimate the driver torque, and can accurately detect that a driver holds the steering wheel **12** and that the driver steers the steering wheel **12**.
Second Embodiment
(102) The steer-by-wire control device according to the second embodiment of the present invention will be described. In the steer-by-wire control device according to the present embodiment, the control device **19** can detect a change in rotational friction of the steering shaft **13** and a change in an attachment angle of the steering wheel **12** based on the method for detecting a change in the moment of inertia described in the first embodiment. By detecting these, for example, influence of aging of the steering shaft **13** due to rotational friction and influence of adjustment of an attachment angle of the steering wheel **12** can be known.
(103) FIG. **8**A is a diagram illustrating the balance of torque around the steering wheel **12** in a case where a friction torque Tf and a gravitational torque Tg are considered in addition to the driver torque Ts, the motor torque Tm, and the inertia torque Tj. The driver torque Ts, the motor torque Tm, and the inertial torque Tj are described in the first embodiment. The friction torque Tf is torque generated in a bearing portion of the steering shaft **13** or the like. The gravitational torque Tg is torque generated by a change in a position of the center of gravity of the steering wheel **12**. The friction torque Tf and the gravitational torque Tg are included in control parameters of a steering wheel.
(104) FIG. **8**B is a diagram for explaining the gravitational torque Tg. When the steering wheel **12** rotates, a position of the center of gravity Gs of the steering wheel **12** changes, and the gravitational torque Tg is generated. The gravitational torque Tg is generated by gravity acting on the center of gravity Gs of the steering wheel **12**, and is considered to change mainly when an attachment angle of the steering wheel **12** in a tilt direction changes.
(105) In the present embodiment, the control device **19** considers the balance of torque illustrated in FIG. **8**A when estimating the driver torque Ts. The balance of torque around the steering wheel **12** is expressed by Equation (3).
(106) $Ts = Tm - Tj - Tf - Tg \quad (3)$
(107) In the present embodiment, the control device **19** can estimate the driver torque Ts with higher accuracy by considering the friction torque Tf and the gravitational torque Tg.
(108) In a state where a driver does not touch the steering wheel **12**, the driver torque Ts is zero, and thus Equation (3) is expressed by Equation (4).
(109) $Tm = Tj + Tf + Tg \quad (4)$
(110) That is, in a case where the driver torque Ts is zero, the motor torque Tm is balanced with the sum (Tj+Tf+Tg) of the inertia torque Tj, the friction torque Tf, and the gravitational torque Tg. Therefore, considering what is described in the first embodiment, the control device **19** can detect not only a change in the moment of inertia but also a change in the friction torque Tf and the gravitational torque Tg from behavior of the steering wheel **12** obtained with respect to the reference torque by applying the reference torque (input torque) to the steering wheel **12**.
(111) Furthermore, in a case where the control device **19** applies the reference torque that causes the steering wheel **12** to rotate at a constant speed, an angular acceleration of the steering wheel **12** becomes zero, and thus, the inertia torque Tj becomes zero, and the motor torque Tm is balanced with the sum (Tf+Tg) of the friction torque Tf and the gravitational torque Tg as shown in Equation (5).

(112) $\mathrm{Tm} = Tf + \mathrm{Tg}$ (5)

(113) Therefore, the control device **19** can detect a change in the friction torque Tf and the gravitational torque Tg from behavior of the steering wheel **12** obtained with respect to the reference torque for rotating the steering wheel **12** at a constant speed, and can obtain a change in rotational friction of the steering shaft **13** and a change in an attachment angle of the steering wheel **12**.

(114) In the steer-by-wire control device according to the present embodiment, the control device **19** can accurately detect a change in rotational friction of the steering shaft **13** and a change in an attachment angle of the steering wheel **12** by a method that hardly gives uneasiness or discomfort to a driver of a vehicle. For this reason, the steer-by-wire control device according to the present embodiment can accurately estimate the driver torque, and can accurately detect that a driver holds the steering wheel **12** and that the driver steers the steering wheel **12**.

(115) Note that the present invention is not limited to the above embodiment, and various variations are possible. For example, the above embodiment is described in detail for easy understanding of the present invention, and the present invention is not necessarily limited to a mode that includes the entirety of the described configurations. Further, a part of a configuration of one embodiment can be replaced with a configuration of another embodiment. Further, a configuration of an embodiment can be added to a configuration of another embodiment. Further, for a part of a configuration of each embodiment, other configurations can be added or replaced with.

REFERENCE SIGNS LIST

(116) **10** steered wheel **11** tie rod **12** steering wheel **13** steering shaft **14** rotation angle sensor **15** current sensor **16** steering mechanism **17** steering axle **17***a*, **17***b* steering axle side ball screw groove **18** reaction force electric motor **19** control device **20** external sensor **21** steering electric motor mechanism **22** rack position sensor **23** motor driver **24** motor driver **25** vehicle speed sensor **26** yaw rate sensor **27** automatic steering system **30** steering axle accommodation portion **31** speed reducer accommodation portion **32** housing **33** speed reduction mechanism **35** steering electric motor **36** screw mechanism **37** steering nut **38** output pulley **39** input pulley **40** belt **44** steering actuator control device

Claims

1. A steer-by-wire control device comprising: a first motor that operates a steering wheel of a vehicle; a second motor that controls steering operation of a wheel of the vehicle; and a control device that controls the first motor and the second motor, wherein the control device applies predetermined input torque to the steering wheel by the first motor in both a forward rotation direction and a backward rotation direction of rotation directions of the first motor before the vehicle makes a transition to an automatic driving mode, the control device acquires behavior information that is information about behavior of the steering wheel obtained by application of the input torque, the control device determines whether or not to make a transition to a control parameter estimation mode for estimating a control parameter of the steering wheel based on the behavior information, and the behavior information includes at least one of a value of a rotation angle of the steering wheel and a value obtained by time-differentiating the rotation angle.
2. The steer-by-wire control device according to claim 1, wherein the control device estimates moment of inertia of the steering wheel based on the behavior information in a case of determining to make a transition to the control parameter estimation mode.
3. The steer-by-wire control device according to claim 1, wherein the input torque has an impulse waveform.
4. The steer-by-wire control device according to claim 1, wherein the input torque has a sinusoidal

waveform.
5. The steer-by-wire control device according to claim 1, wherein the control device compares current behavior information that is the behavior information acquired by application of the input torque with previous behavior information that is the behavior information acquired by application of the input torque at a previous time, obtains a change amount of the current behavior information from the previous behavior information, and determines whether or not to make a transition to the control parameter estimation mode based on the change amount.
6. The steer-by-wire control device according to claim 5, wherein the control device determines whether or not to make a transition to the control parameter estimation mode based on an absolute value of the change amount.
7. The steer-by-wire control device according to claim 5, wherein the control device makes a transition to the control parameter estimation mode in a case where the change amount is larger than a predetermined first threshold.
8. The steer-by-wire control device according to claim 7, wherein the control device makes a transition to the control parameter estimation mode in a case where the change amount is equal to or less than a predetermined second threshold.
9. The steer-by-wire control device according to claim 8, wherein the control device causes the vehicle to make a transition to the automatic driving mode in a case where the change amount is equal to or less than the first threshold, and cancels a request for automatic driving from a driver of the vehicle in a case where the change amount is larger than the second threshold.
10. The steer-by-wire control device according to claim 5, wherein the control device estimates moment of inertia of the steering wheel based on the change amount in a case of determining to make a transition to the control parameter estimation mode.
11. A steer-by-wire control method executed by a control device that controls a first motor that operates a steering wheel of a vehicle and a second motor that controls steering operation of a wheel of the vehicle, the steer-by-wire control method comprising the steps of: applying predetermined input torque to the steering wheel by the first motor in both a forward rotation direction and a backward rotation direction of rotation directions of the first motor before the vehicle makes a transition to an automatic driving mode; acquiring behavior information that is information about behavior of the steering wheel obtained by application of the input torque; and determining whether or not to make a transition to a control parameter estimation mode for estimating a control parameter of the steering wheel based on the behavior information, wherein the behavior information includes at least one of a value of a rotation angle of the steering wheel and a value obtained by time-differentiating the rotation angle.