United States Patent	12391243
Kind Code	B2
Date of Patent	August 19, 2025
Inventor(s)	Hamaguchi; Takeshi et al.

Control device for vehicle and control method for vehicle

Abstract

A control device for a vehicle configured to execute a first control for outputting a steering torque based on a predetermined first gain and a second control for outputting a steering torque based on a predetermined second gain different from the first gain, wherein during execution of the first control, a predicted start time, which is a predicted time until the start condition of the second control is satisfied, is calculated, and when the start predicted time satisfies the predetermined condition, a reduction control for bringing the output steering torque of the first control closer to 0 is executed before starting the second control.

Inventors: **Hamaguchi; Takeshi (Seto, JP), Saigo; Shintaro (Nisshin, JP), Sugamoto; Shusaku (Toyota, JP)**

Applicant: **TOYOTA JIDOSHA KABUSHIKI KAISHA** (Toyota, JP)

Family ID: **1000008768181**

Assignee: **TOYOTA JIDOSHA KABUSHIKI KAISHA (Toyota, JP)**

Appl. No.: **18/446736**

Filed: **August 09, 2023**

Prior Publication Data

Document Identifier	Publication Date
US 20240182021 A1	Jun. 06, 2024

Foreign Application Priority Data

JP	2022-167408	Oct. 19, 2022

Publication Classification

Int. Cl.: **B60W30/09** (20120101); **B60W30/095** (20120101); **B60W30/12** (20200101); **B60W50/16** (20200101); **B62D15/02** (20060101)

U.S. Cl.:

CPC **B60W30/09** (20130101); **B60W30/095** (20130101); **B60W30/0956** (20130101); **B60W30/12** (20130101); **B60W50/16** (20130101); **B62D15/0265** (20130101); B60W2540/18 (20130101); B60W2710/202 (20130101)

Field of Classification Search

CPC: B62D (15/025); B62D (15/0265); B62D (6/00); B60W (30/09); B60W (30/095); B60W (30/0956); B60W (30/12); B60W (50/16)

USPC: 701/45

References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
7692534	12/2009	Kataoka et al.	N/A	N/A
8352124	12/2012	Taguchi	N/A	N/A
8682500	12/2013	Sakugawa	N/A	N/A
8818634	12/2013	Fujita et al.	N/A	N/A
9168953	12/2014	Mitsumoto et al.	N/A	N/A
9321484	12/2015	Morotomi	N/A	B62D 6/002
9327765	12/2015	Takeda	N/A	B62D 6/04
9714034	12/2016	Otake et al.	N/A	N/A
9880558	12/2017	Nakamura	N/A	N/A
9902399	12/2017	Torii et al.	N/A	N/A
10345443	12/2018	Masui et al.	N/A	N/A
10611240	12/2019	Masui et al.	N/A	N/A
11352058	12/2021	Hayashi	N/A	B62D 15/025
2003/0060936	12/2002	Yamamura	348/148	B62D 15/0265
2003/0078712	12/2002	Shimakage	701/41	B62D 1/286
2009/0024279	12/2008	Takeda	701/41	B62D 6/008
2009/0048738	12/2008	Iwazaki	701/44	B62D 1/28
2010/0138112	12/2009	Suzuki	701/42	B62D 15/025
2013/0190988	12/2012	Limpibunterng	701/42	B62D 5/008
2015/0210318	12/2014	Takeda	701/41	B62D 6/008
2016/0001811	12/2015	Endo	701/41	B62D 6/10
2016/0114832	12/2015	Taniguchi	701/41	B62D 6/04
2017/0066475	12/2016	Kudo	N/A	B62D 6/10
2017/0066476	12/2016	Kudo	N/A	B62D 5/0463
2017/0088167	12/2016	Fujii	N/A	B62D 1/286
2018/0015947	12/2017	Akatsuka	N/A	B62D 6/008
2018/0086341	12/2017	Taniguchi	N/A	B62D 6/008
2018/0201318	12/2017	Kataoka	N/A	G06V 20/588
2019/0367082	12/2018	Sugamoto	N/A	B60W 50/087
2020/0023884	12/2019	Mizoo	N/A	B60W 30/095

| 2020/0207341 | 12/2019 | Inoue | N/A | B60W 30/18145 |
| 2021/0309292 | 12/2020 | Suzuki | N/A | B62D 6/008 |

FOREIGN PATENT DOCUMENTS

Patent No.	Application Date	Country	CPC
2015-093569	12/2014	JP	N/A
2019-209844	12/2018	JP	N/A
2020-185920	12/2019	JP	N/A
WO-2006081936	12/2005	WO	B60T 8/1755
WO-2011161535	12/2010	WO	B62D 15/025

Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION
(1) This application claims priority to Japanese Patent Application No. 2022-167408 filed on Oct. 19, 2022, incorporated herein by reference in its entirety.
BACKGROUND
1. Technical Field
(2) The present disclosure relates to a control device and a control method for a vehicle.
2. Description of Related Art
(3) Japanese Unexamined Patent Application Publication No. 2019-209844 (JP 2019-209844 A) discloses a driving assistance device that predicts the amount of operation of the driver according to the external environment, calculates the amount of deviation from the actual amount of operation of the driver, and changes a reaction force characteristic of the operation unit to a reaction force characteristic corresponding to the amount of deviation to optimize the amount of operation of the driver.
SUMMARY
(4) In a driving assistance device capable of executing a plurality of steering controls as driving assistance, there is a case where the steering control being executed is switched to another steering control. In general, since the plurality of steering controls has different objectives, the steering angle followability with respect to the target steering angle is also different. Therefore, when the steering control being executed is switched to another steering control having a different steering angle followability, there is a problem in that the steering torque suddenly changes with the switching of the control, thereby giving a sense of discomfort to the occupant of the vehicle including the driver.
(5) An object of the present disclosure is to provide a technique capable of effectively suppressing fluctuations in steering torque caused by switching of control.
(6) The present disclosure is a control device and a control method for a vehicle, the control device and the control method being able to execute first control for outputting a steering torque based on a predetermined first gain and second control for outputting a steering torque based on a predetermined second gain that differs from the first gain. During execution of the first control, a start prediction time that is a predicted time until a start condition of the second control is satisfied

is calculated, and when the start prediction time satisfies a predetermined condition, before starting the second control, degeneracy control for bringing an output steering torque of the first control close to zero is executed.

(7) According to the control device and the control method described above, when the steering control is switched to the second control whose gain is different from the first control during the execution of the first control, the degeneracy control for bringing the output steering torque of the first control closer to 0 is executed before the start of the second control. As a result, it is possible to effectively suppress fluctuations in the steering torque caused by switching of the control, and it is possible to effectively suppress giving an uncomfortable feeling to the occupant of the vehicle.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) Features, advantages, and technical and industrial significance of exemplary embodiments of the disclosure will be described below with reference to the accompanying drawings, in which like signs denote like elements, and wherein:

(2) FIG. **1** is a schematic diagram illustrating a hardware configuration of a vehicle according to the present embodiment;

(3) FIG. **2** is a schematic diagram illustrating a software configuration of the control device according to the present embodiment;

(4) FIG. **3** is a schematic diagram illustrating travel lane information;

(5) FIG. **4** is a timing chart illustrating the switching control according to the present embodiment;

(6) FIG. **5** is a flowchart illustrating a routine of switching control according to the present embodiment; and

(7) FIG. **6** is a timing chart illustrating the switching control of the comparative example.

DETAILED DESCRIPTION OF EMBODIMENTS

(8) Hereinafter, a vehicle control device and a control method according to the present embodiment will be described with reference to the drawings.

Hardware Configuration

(9) FIG. **1** is a schematic diagram illustrating a hardware configuration of a vehicle SV to which a control device according to the present embodiment is applied.

(10) The vehicle SV has an Electronic Control Unit (ECU) **10**. ECU **10** includes a Central Processing Unit (CPU) **11**, Read Only Memory (ROM) **12**, Random Access Memory (RAM) **13**, an interface device **14**, and the like. CPU **11** is a processor that executes various programs stored in ROM **12**. ROM **12** is a non-volatile memory that stores data and the like required for CPU **11** to execute various programs. RAM **13** provides a working area to be deployed when various programs are executed by CPU **11**. The interface device **14** is a communication device for communicating with an external device.

(11) ECU **10** is a central device that supports driving by a driver of a vehicle SV. ECU **10** can execute the normal support mode in which the degree of the steering intervention is relatively small and the avoidance support mode in which the degree of the steering intervention is relatively large as the driving assistance, and can switch between the normal support mode and the avoidance support mode.

(12) The normal support mode is a mode in which driver-based driving support is performed. In the present embodiment, the reaction force control for changing the reaction force characteristic of the steering operation unit is performed so that the steering operation amount of the driver becomes an appropriate operation amount. The avoidance support mode is a mode in which the system-based driving support is performed. In the present embodiment, a Lane Departure Alert Control (hereinafter, referred to as LDA control) is performed to suppress the vehicle SV from deviating

from the travel lane. The reaction force control and LTA control will be described later.

(13) A drive device **20**, a braking device **21**, a steering device **22**, an internal sensor device **30**, an external sensor device **40**, and the like are communicably connected to ECU **10**.

(14) The driving device **20** generates a driving force to be transmitted to the driving wheels of the vehicle SV. Examples of the drive device **20** include an electric motor and an engine. In the present embodiment, the vehicle SV may be any of a hybrid electric vehicle (HEV), a plug-in hybrid vehicle (PHEV), a fuel cell electric vehicle (FCEV), a battery electric vehicle (BEV), and an engine-driven vehicle. The braking device **21** applies a braking force to the wheels of the vehicle SV.

(15) The steering device **22** applies a steering force to the wheels of the vehicle SV. The steering device **22** may be either a rack-and-pinion type or a steering-by-wire type. The steering device **22** includes a steering operation unit **23** including a steering wheel SW and the like. Further, the steering device **22** includes a steering motor **25** that applies steering torque to the steering shaft **24**. The steering motor **25** generates a steering torque in response to a command from ECU **10**. This steering torque can steer the left and right steered wheels of the vehicle SV, and furthermore, it is possible to apply a reaction force to the steering wheel SW against the driver's manipulation. Note that the steering operation unit **23** is not limited to the steering wheel SW, and may be shaped other than a wheel, such as a steering rod.

(16) The internal sensor device **30** is a sensor that detects the condition of the vehicle SV. Specifically, the internal sensor device **30** includes a vehicle speed sensor **31**, a steering angle sensor **32**, a yaw rate sensor **33**, an acceleration sensor **34**, and the like.

(17) The vehicle speed sensor **31** detects a traveling speed (vehicle speed V) of the vehicle SV. The steering angle sensor **32** detects a rotational angle of a steering wheel or a steering shaft (not shown) of the vehicle SV, that is, a steering angle. The yaw rate sensor **33** detects the yaw rate of the vehicle SV. The acceleration sensor **34** detects an acceleration of the vehicle SV. The internal sensor device **30** transmits the condition of the vehicle SV detected by the sensors **31** to **34** to ECU **10** at a predetermined cycle.

(18) The external sensor device **40** is a sensor or the like that recognizes target information related to a target in the vicinity of SV. Specifically, the external sensor device **40** includes a radar sensor **41**, a camera sensor **42**, and the like. Here, the target information includes, for example, a surrounding vehicle, a dividing line such as a white line drawn on a road surface, a curb, a guardrail, a wall, and the like. The external sensor device **40** repeatedly transmits the acquired target object data to ECU **10** every time a predetermined period elapses.

(19) The radar sensor **41** is provided, for example, at a front portion of the vehicle SV, and detects a target present in a front area of the vehicle SV. The radar sensor **41** includes a millimeter wave radar and/or a lidar. The millimeter wave radar emits a millimeter wave and receives a millimeter wave (reflected wave) reflected by a target object existing in a radiation range. The millimeter wave radar acquires the relative distance between the vehicle SV and the target, the relative velocity between the vehicle SV and the target, and the like based on the phase difference between the transmitted millimeter wave and the received reflected wave, the attenuation level of the reflected wave, the time from the transmission of the millimeter wave until the reception of the reflected wave, and the like. The lidar sequentially scans pulsed laser beams having a shorter wavelength than millimeter waves toward a plurality of directions, and receives the reflected light reflected by the targets, thereby obtaining shapes of the targets detected in front of the vehicle SV, relative distances between the vehicle SV and the targets, relative velocities between the vehicle SV and the targets, and the like.

(20) The camera sensor **42** is, for example, a stereo camera or a monocular camera, and a digital camera having an image sensor such as a CMOS or a CCD can be used. The camera sensor **42** is disposed, for example, on an upper portion of a windshield glass of a vehicle SV. The camera sensor **42** captures an image in front of the vehicle SV and processes the captured image-data to

acquire target information in front of the vehicle SV. The target information is information indicating a type of a target detected in front of the vehicle SV, a relative distance between the vehicle SV and the target, a relative velocity between the vehicle SV and the target, and the like. The type of the target may be recognized by machine learning such as pattern matching, for example.

Software Configuration

(21) FIG. **2** is a schematic diagram illustrating a software configuration of ECU **10** according to the present embodiment. As illustrated in FIG. **2**, ECU **10** includes a lane-recognizing unit **100**, a reaction force control unit **110**, a LDA control unit **120**, a switching control unit **130**, and the like as functional elements. These functional elements **100** to **130** are realized by CPU **11** of ECU **10** reading a program stored in ROM **12** into a RAM **13** and executing the program. It should be noted that although the functional elements **100** to **130** are described as being included in an ECU **10** which is integral hardware in the present embodiment, any one of them may be provided in another ECU separate from ECU **10**. In addition, all or a part of the functional elements **100** to **130** of ECU **10** may be provided in an information processing device of a facility (for example, a managing center) capable of communicating with the vehicle SV.

(22) The lane recognition unit **100** recognizes the traveling lane in which the vehicle SV is traveling, based on the detection result of the external sensor device **40**. Here, the traveling lane refers to a traveling area defined by a structure such as a curbstone, a guardrail, or a wall as well as a dividing line such as a white line or a yellow line drawn on a road surface. In the following description, for the sake of convenience, the boundary of the traveling region defined by the dividing lines, structures, and the like is referred to as a "boundary line".

(23) As illustrated in FIG. **3**, the lane recognition unit **100** recognizes the left boundary line LL and the right boundary line LR. Further, the lane recognition unit **100** calculates the curve radius R of the center line LC that is the center position of the left and right boundary lines LL, LR, and calculates the deviation angle θy (yaw angle θy) between the direction of the center line LC and the direction in which the vehicle SV is directed. Further, the lane recognition unit **100** calculates a distance (hereinafter, referred to as a lateral deviation Δx) between the left front wheel and the left boundary line LL of the vehicle SV and between the right front wheel and the right boundary line LR. FIG. **3** shows only the lateral deviation Δx between the left front wheel and the left boundary line LL. In this case, there are two lateral deviations Δx. In LDA control described later, the lateral deviation Δx in the direction in which SV of vehicles is estimated to deviate from the traveling lane, that is, the direction indicated by the yaw angle θy may be used. Hereinafter, the lateral deviation Δx, the yaw angle θy, and the curve radius R calculated by the lane recognition unit **100** are also collectively referred to as traveling lane information.

(24) When the driving support is the normal support mode, the reaction force control unit **110** executes reaction force control for changing the reaction force property of the steering operation unit **23** so that the operation quantity of the steering wheel SW of the driver becomes appropriate while maintaining the driver's main sensation. The reaction force characteristic is a characteristic of the reaction force applied from the steering motor **25** to the steering shaft **24** in accordance with the manipulated variable of the driver with respect to the steering wheel SW.

(25) The reaction force control unit **110** predicts an appropriate operation amount of the driver based on the detection result of the internal sensor device **30** and the traveling lane information acquired by the lane recognition unit **100**. The proper manipulation amount is a manipulation amount of the steering wheel SW that is normally performed by the driver in response to conditions around the vehicle SV. The reaction force control unit **110** compares the predicted proper operation amount with the actual operation amount (actual operation amount) of the driver. The operation amount of the driver may be acquired based on the detection result of the steering angle sensor **32**.

(26) When the actual operation amount is an appropriate operation amount, the reaction force control unit **110** maintains the reaction force characteristic of the steering operation unit **23** at a

predetermined reference reaction force characteristic. On the other hand, when the actual operation amount is not the proper operation amount, the reaction force control unit **110** changes the reaction force characteristic of the steering operation unit **23** from the reference reaction force characteristic to the main body feeling maintaining reaction force characteristic. The main body feeling maintaining reaction force characteristic is a reaction force characteristic that makes the actual operation amount easily stay at an appropriate operation amount while maintaining the main body feeling of the driver, and can be set by a minute change from the reference reaction force characteristic. As an example, the reaction force maintaining reaction force characteristic can be set by making the reaction force change amount when the actual operation amount is in the proper operation amount larger than the reaction force change amount when the actual operation amount is deviating from or is likely to deviate from the proper operation amount.

(27) When the reaction force characteristic is changed to the main body feeling maintaining reaction force characteristic, the reaction force control unit **110** calculates a target steering angle of the reaction force control (hereinafter, the reaction force target steering angle σA) based on the main body feeling maintaining reaction force characteristic. Further, the reaction force control unit **110** calculates the reaction force support torque τSA (=τA(σA−σD)) by multiplying the steering angle difference Δσ between the reaction force target steering angle σA and the actual steering angle σD acquired by the steering angle sensor **32** by a predetermined torque gain (hereinafter, referred to as reaction torque gain τA). Further, the reaction force control unit **110** transmits a command signal including information indicating the reaction force support torque τSA to the steering device **22**. Accordingly, the reaction force support torque τSA is transmitted from the steering motor **25** to the steering shaft **24**, and a desired reaction force is applied to the steering wheel SW.

(28) LDA control unit **120** executes LDA control for suppressing a deviation of the vehicle SV from the traveling lane when the vehicle SV is likely to deviate from the traveling lane. LDA control unit **120** calculates a target steering angle of LDA control (hereinafter, referred to as a LDA target steering angle σB) based on the travel lane information (Δx, θY, R) acquired by the lane recognition unit **100**. LDA target steering angle σB is a steering angle that is set so that the vehicle SV does not deviate outward in the boundary line LL, LR.

(29) LDA control unit **120** determines whether LDA starting condition is satisfied. LDA starting condition may be, for example, a case where the predicted arrival time TR until the vehicle SV reaches the boundary line LL, LR becomes shorter than the predetermined threshold time Tv (TR<Tv). The predicted arrival-time TR can be determined based on Equation (1) below, which assumes that the vehicle SV performs isoaccelerated linear motion until reaching the boundary line LL, LR.

(30) Mathematical Formula 1

(31) $\mathrm{TR} = \dfrac{-\frac{d}{dt}x \pm \sqrt{\left(\frac{d}{dt}x\right)^3 - 2\mathrm{YR} \times V \times\ x}}{\mathrm{YR} \times V} \quad \therefore \quad x = \frac{d}{dt}x \times \mathrm{TR} + \frac{1}{2} \times (\mathrm{YR}\ .\mathrm{Math.}\ V) \times \mathrm{TR} \times \mathrm{TR}^2$ (1)

In Equation (1), Δx is the lateral deviation, V is the vehicle speed of the vehicle SV, and YR is the yaw rate of the vehicle SV.

(32) When LDA starting condition is satisfied, LDA control unit **120** calculates LDA support torque τSB (=τB(σB−σD)) by multiplying the steering angle difference Δσ between LDA target steering angle σB and the actual steering angle σD acquired by the steering angle sensor **32** by a predetermined torque gain (hereinafter, referred to as a LDA torque gain τB). When LDA support torque TSB is calculated, LDA control unit **120** transmits a command signal including information representing LDA support torque τSB to the steering device **22**. As a result, LDA support torque τSB is transmitted from the steering motor **25** to the steering shaft **24**, and the steered wheels of the vehicle SV are steered, so that the vehicle SV is prevented from deviating from the traveling lane.

(33) Here, it is assumed that the driving support is switched from the normal support mode to the avoidance support mode, that is, the steering control transitions from the reaction force control to

LDA control. The reaction force control is a driver-based driving support that has low steering angle followability with respect to the target steering angle, and LDA control is a system-based driving support that has high steering angle followability with respect to the target steering angle. In general, the smaller the torque gain, the lower the steering angle followability with respect to the target steering angle, and the larger the steering angle difference between the target steering angle and the actual steering angle. On the other hand, as the torque gain increases, the steering angle followability with respect to the target steering angle increases, and the steering angle difference between the target steering angle and the actual steering angle decreases. Therefore, when the steering control is switched from the reaction force control with low steering angle followability to LDA control with high steering angle followability, it is conceivable that the target steering angle is gradually changed and the steering angle is smoothly connected.

(34) FIG. **6** is a timing chart illustrating an exemplary process of smoothly connecting the steering angles when the steering control is switched from the reaction force control to LDA control. FIG. **6** is a comparative example of the present disclosure. From the time t**1** in FIG. **6**, t**2** indicates a gradual change period in which the target steering angle (refer to σS) is gradually changed from the reaction force target steering angle σA toward LDA target steering angle σB in order to smoothly connect the steering angles. Since LDA control has higher steering angle followability than the reaction force control, LDA torque gain τB is larger than the reaction force torque gain τA (τA<τB). Therefore, even if a gradual change period for gradually changing the target steering angle is provided, the output steering torque greatly changes from the reaction force support torque τSA (=τA (σA−σD)) to LDA support torque τSB (=τB (σB−σD)) before and after the switching of the control, so that a sudden torque change occurs (refer to α in FIG. **6**). When a sudden torque change occurs, there is a problem that an occupant including a driver feels uncomfortable or uncomfortable. In addition, there is also a problem that LDA target steering angle σB indicated by a broken line in FIG. **6** greatly deviates from the actual steering angle σD, thereby deteriorating the steering angle followability of LDA control (see β in FIG. **6**).

(35) Therefore, the switching control unit **130** of the present embodiment performs the pre-degeneracy control of bringing the reaction force support torque τSA closer to 0 (zero) prior to switching the reaction force control to LDA control, so as to suppress the torque sudden change caused by the switching of the control. Details of the pre-degeneracy control will be described below based on a timing chart shown in FIG. **4**.

(36) In the time t**0** of FIG. **4**, it is assumed that the driving support is the normal support mode and the reaction force control is executed. During the execution of the reaction force control, the switching control unit **130** repeatedly calculates the steering angle difference Δσ between the reaction force target steering angle σA and the actual steering angle σD at a predetermined cycle. Further, the switching control unit **130** repeatedly calculates a predicted time (hereinafter, referred to as a "start prediction time TB") from the present time until the start condition of LDA control is satisfied at a predetermined cycle. The start prediction time TB is a time from the present time until the predicted arrival time TR becomes shorter than the threshold time Tv.

(37) The switching control unit **130** calculates a prediction time (hereinafter, referred to as a degeneracy prediction time Td) required to bring the present reaction force support torque τSA to approximately 0 (zero) based on the preset torque gradually decreasing gradient τgr. The torque decreasing gradient τgr is a torque change rate (change amount per unit time) that gradually decreases the reaction force support torque τSA to 0 (zero), and is set based on a value that does not give a driver a sense of discomfort or minimizes a sense of discomfort. The torque decreasing gradient τgr may be a fixed value or may be a variable value corresponding to the steering angle difference Δσ.

(38) The switching control unit **130** calculates the degeneracy prediction time TD (=Δσ/τgr) by dividing the steering angle difference Δσ by the torque gradually decreasing gradient τgr. The switching control unit **130** determines whether or not the degeneracy prediction time TD is equal to

or greater than the start prediction time TB. The switching control unit **130** starts the pre-degeneracy control from the time t**1** when the degeneracy prediction time TD becomes equal to or larger than the start prediction time TB at t**1** (TD≥TB).

(39) The switching control unit **130** determines whether or not the steering angle difference Δσ becomes 0 (zero) by executing the pre-degeneracy control. At the time t**2**, when the steering angle difference Δσ becomes 0 (zero), and accordingly, the reaction force support torque τSA also becomes approximately 0 (zero), the switching control unit **130** ends the pre-degeneracy control. At the same time, the switching control unit **130** starts LDA control, that is, switches the steering control from the reaction force control to LDA control. As described above, by starting LDA control while the reaction force support torque τSA is approximately 0 (zero), even when the steering angle followability (torque gains τA and τB) of the reaction force control and LDA control differ, the generation of torque fluctuation due to the switching can be effectively suppressed. In addition, by starting LDA control from a condition in which the steering angle difference Δσ is 0 (zero), the steering angle followability of LDA control can be effectively ensured. Further, as long as the time until the reaction force support torque τSA reaches approximately 0 (zero) remains, the reaction force control can be continued to ensure the maximum operation time of the reaction force control.

(40) FIG. **5** is a flow chart for explaining a routine of switching control by CPU **11** of an ECU **10**. This routine is started by executing the reaction force control.

(41) In S**100**, ECU **10** determines whether or not the reaction force control is being executed. If the reaction force control is being executed (Yes), ECU **10** proceeds to S**110** process. On the other hand, when the reaction force control is not being executed (No), ECU **10** returns this routine.

(42) In S**110**, ECU **10** calculates a steering angle difference Δσ between the reaction force target steering angle σA and the actual steering angle σD, and calculates a start prediction time TB from the present time until the start condition of LDA control is satisfied. Next, in S**120**, ECU **10** determines whether or not the degeneracy prediction time TD (=Δσ/τgr) obtained by dividing the steering angle difference Δσ by the torque gradual decreasing gradient τgr becomes equal to or larger than the start prediction time TB. If the degeneracy prediction time TD becomes equal to or greater than the start prediction time TB (Yes), ECU **10** proceeds to S**130** process. On the other hand, when the degeneracy prediction time TD is shorter than the start prediction time TB (No), ECU **10** returns to S**100** determination process.

(43) In S**130**, ECU **10** executes a pre-degeneracy control for bringing the reaction force support torque τSA close to approximately 0 (zero) based on the torque gradual decreasing gradient τgr. Then, in S**140**, ECU **10** determines whether or not the steering angle difference Δσ becomes 0 (zero) by executing the pre-degeneracy control. If the steering angle difference Δσ is not 0 (No), ECU **10** returns to S**130** process and continues the pre-degeneracy control. On the other hand, when the steering angle difference Δσ becomes 0 (Yes), ECU **10** proceeds to S**150** process and starts LDA control. ECU **10** then returns the routine.

(44) Although the control device and the control method of the vehicle according to the present embodiment have been described above, the present disclosure is not limited to the above-described embodiment, and various modifications can be made without departing from the object of the present disclosure.

(45) For example, in the above-described embodiment, the switching control unit **130** executes the pre-degeneration control when the driving support is switched from the normal support mode to the avoidance support mode, that is, when the steering control is shifted from the reaction force control to LDA control, but can also execute the pre-degeneration control when the driving support is switched from the avoidance support mode to the normal support mode, that is, when the steering control is shifted from LDA control to the reaction force control. In this case, too, it is possible to suppress the sudden torque change (sudden decrease) caused by the switching of the control, and it is possible to effectively prevent the driver from feeling uncomfortable.

(46) Further, the avoidance support mode is not limited to LDA control, and may be another steering control with a relatively large degree of steering intervention, such as lane-keeping support control (LTA control) and steering avoidance control (PCS control).

(47) Further, the application of the present disclosure is not limited to the steering control, and can also be applied to a case where two or more controls having different gains are switched to one actuator in the control of a general actuator such as a powertrain. Examples of such control include control for switching the regenerative braking force of the electric motor to a stronger braking force.

(48) The vehicle SV may be a vehicle capable of switching between automated driving and manual driving. In this case, the control of the present disclosure may be executed during the manual operation.

Claims

1. A control device for a vehicle comprising a processor configured to execute first control that outputs a first steering torque based on a first gain and second control that outputs a second steering torque based on a second gain that differs from the first gain, wherein during execution of the first control, the processor is configured to repeatedly calculate a first time that is a predicted time until a start condition of the second control is satisfied, repeatedly calculate a second time that is a predicted time over which the first steering torque reduced to zero at a predetermined gradient, and determine whether the second time becomes equal to or longer than the first time, the processor is configured to keep executing the first control in a case where the processor determines that the second time is shorter than the first time, and the processor is configured to decrease the first steering torque close to zero at the predetermined gradient in a case where the processor determines that the second time becomes equal to or longer than the first time, acquire a steering angle difference between a target steering angle and an actual steering angle, determine whether the steering angle difference becomes zero, and in a case where the processor determines that the steering angle difference becomes zero, execute the second control.

2. The control device according to claim 1, wherein the second gain is larger than the first gain, and the second control is a steering control that has a higher steering angle followability with respect to a target steering angle than the first control.

3. The control device according to claim 1, wherein the first control is a reaction force control for predicting an appropriate operation amount for a steering operation unit of a driver in accordance with a situation around the vehicle, setting an appropriate operation range including the appropriate operation amount, and changing a reaction force characteristic of the steering operation unit such that an operation amount of the driver is within the appropriate operation range, and the second control is any one of a lane deviation suppression control for suppressing a deviation from a traveling lane of the vehicle, a lane maintenance support control for maintaining the vehicle in a traveling lane, and a steering avoidance support control for avoiding a collision between the vehicle and an obstacle.

4. A control method for a vehicle, the control method comprising: executing first control that outputs a first steering torque based on a first gain; during execution of the first control, repeatedly calculating a first time that is a predicted time until a start condition of a second control is satisfied, repeatedly calculating a second time that is a predicted time over which the first steering torque reduced to zero at a predetermined gradient, and determining whether the second time becomes equal to or longer than the first time, in a case where the second time is shorter than the first time, keep executing the first control; and in a case where the second time becomes equal to or longer than the first time, decreasing the first steering torque close to zero at the predetermined gradient, acquiring a steering angle difference that is a difference between a target steering angle and an actual steering angle, determining whether the steering angle difference becomes zero, and in a

case where the steering angle difference becomes zero, executing the second control that outputs a second steering torque based on a second gain that differs from the first gain.

5. The control device according to claim 1, wherein during the first control, the processor is configured to repeatedly calculate a third time that is a predicted time until the time for the vehicle to reach a boundary line of a driving lane, the start condition of the second control will be satisfied in a case where the third time becomes shorter than a threshold, and the first time is the predicted time until the third time becomes shorter than the threshold.

6. The control device according to claim 1, wherein the predetermined gradient is a torque change amount per unit time and set based on a value that does not give a driver a sense of discomfort.