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(54) **TURNING CONTROL DEVICE**

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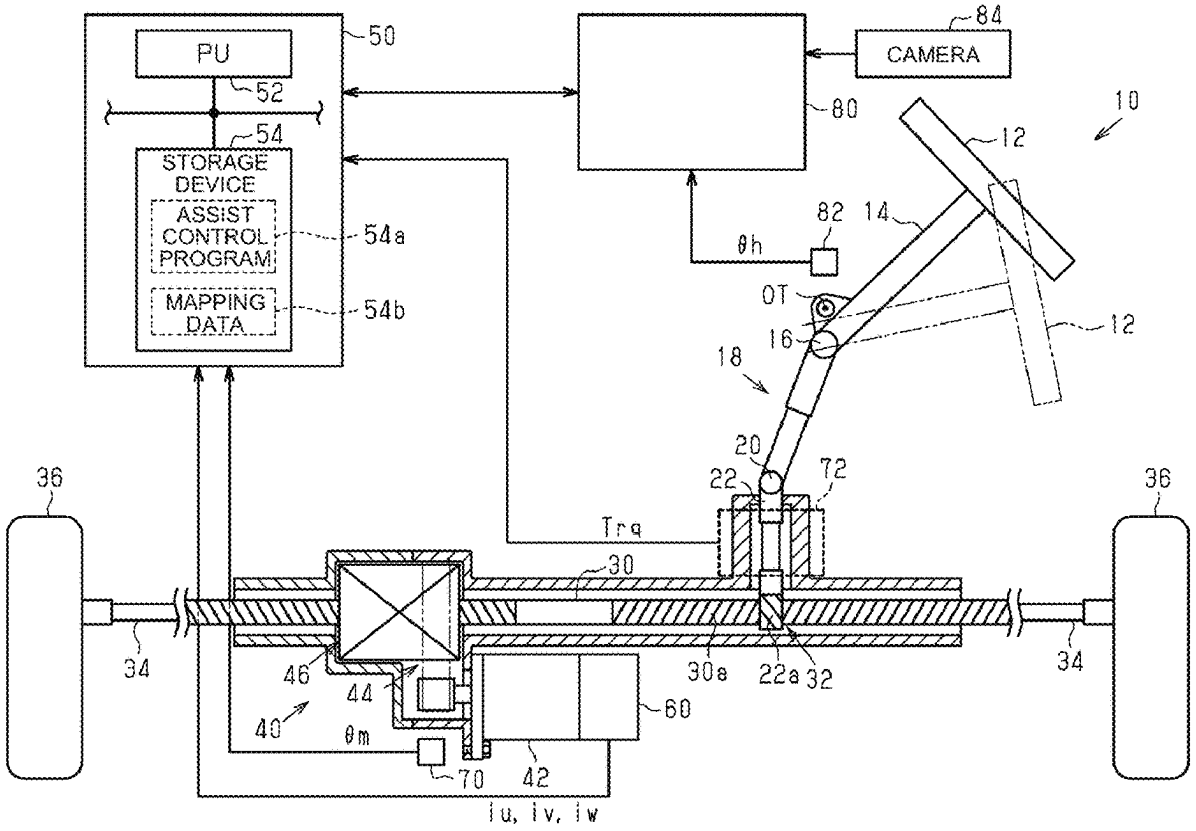
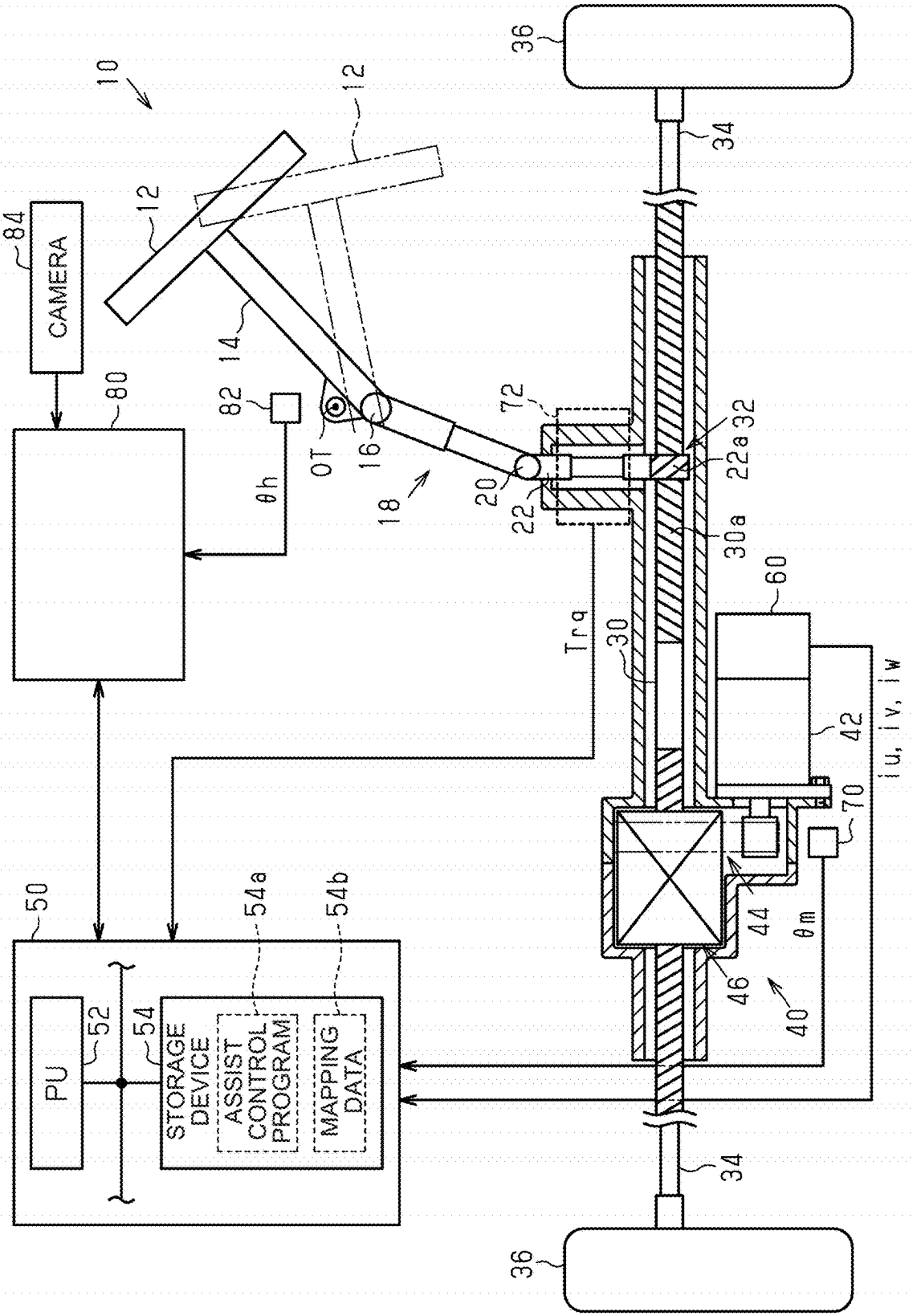
(57) **ABSTRACT**

A processor included in a turning control device is configured to execute a manipulation process of manipulating a drive circuit of an assist motor depending on a torque that depends on at least one of the two values, the value of an assist torque variable and the value of a control torque variable. The processor is configured to execute a variation torque control process of varying a torque as an input variable in the manipulation process, depending on a steering angle, based on the value of the steering angle variable as an input variable. The processor is configured to execute a restriction process of restricting the magnitude of variation in the torque as the input variable in the manipulation process depending on the steering angle, to a small side, depending on the priority degree of the value of the control torque variable in the manipulation process.

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12
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CAMERA
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θh
OT
16
18
20
22
72
22a
32
30a
36
34
60
Trq
30
42
iu, iv, iw
70
44
θm
46
40
50
54a
54b
PU
52
54
STORAGE DEVICE
ASSIST CONTROL PROGRAM
MAPPING DATA
34
36

FIG. 1

FIG. 2

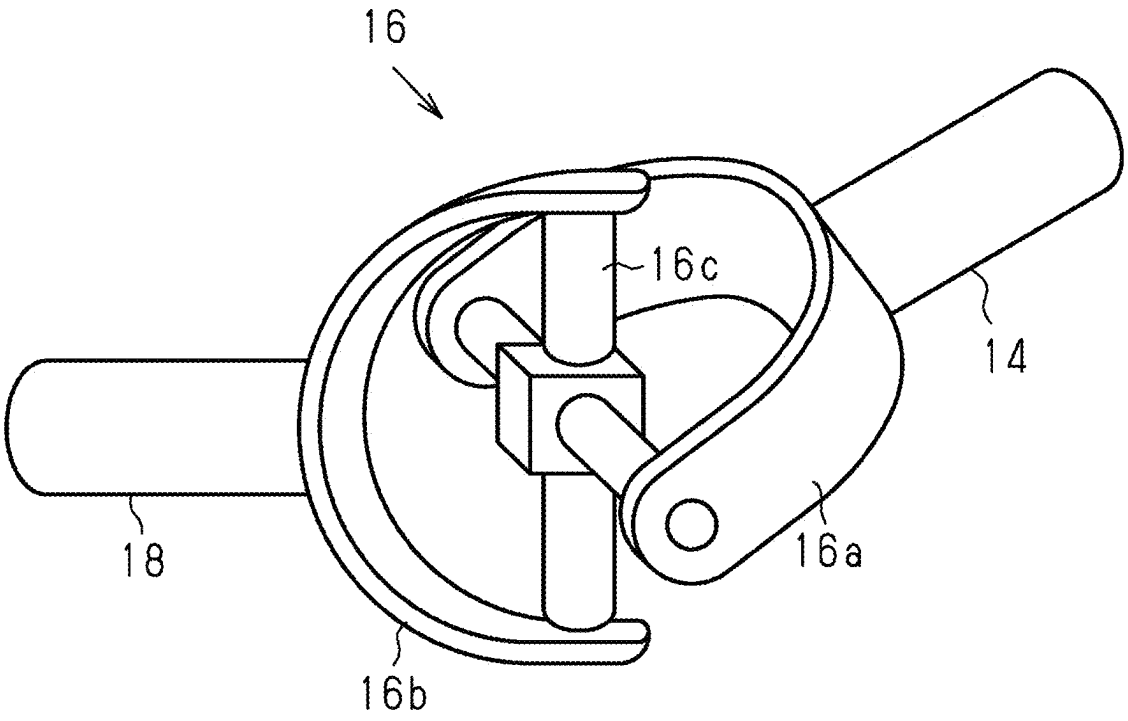


FIG. 3

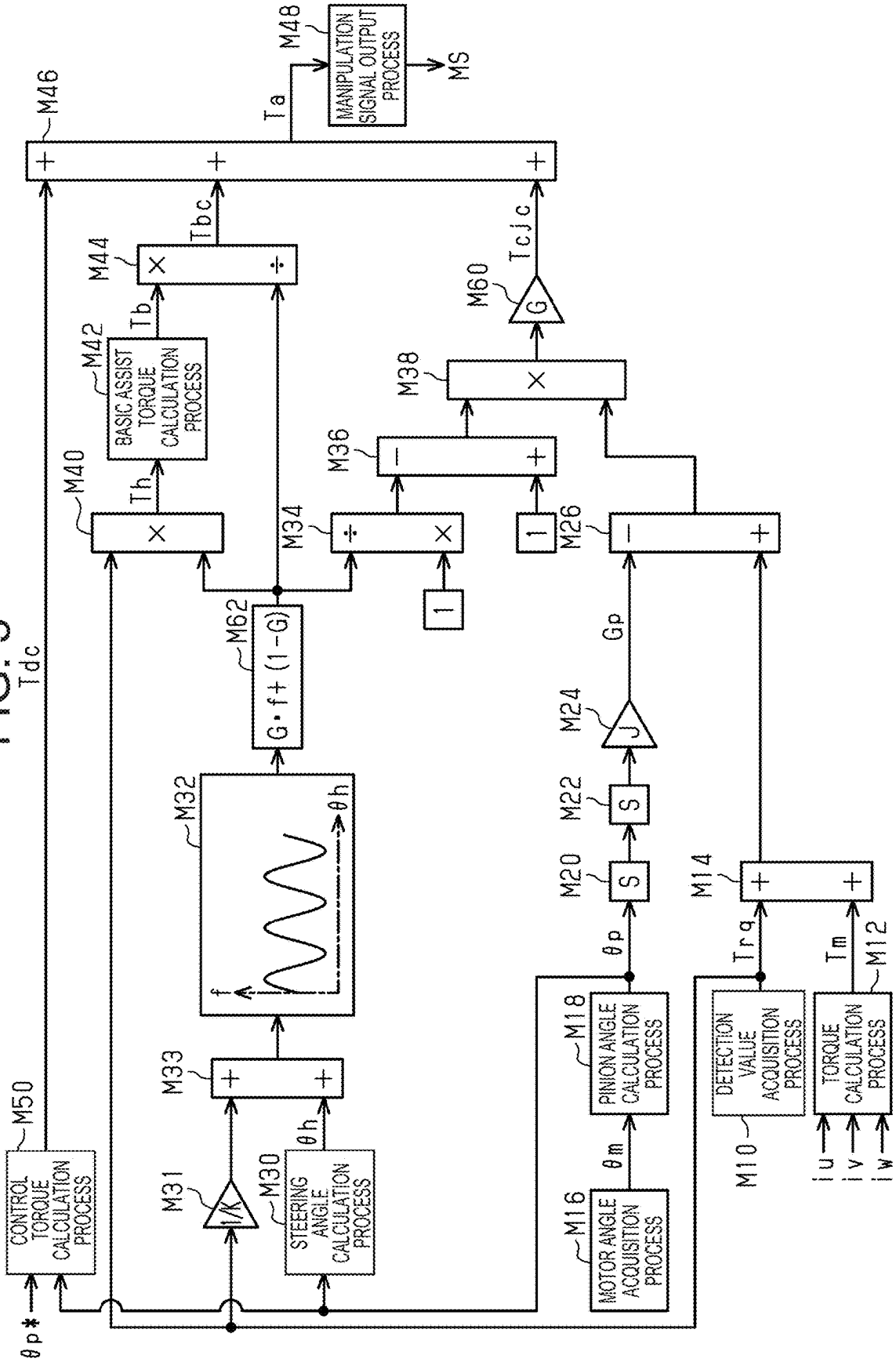

θp*
CONTROL TORQUE CALCULATION PROCESS
M50
Tdc
M31
1/K
M30
STEERING ANGLE CALCULATION PROCESS
θh
M33
M32
f
θh
M62
G・f+(1-G)
M40
Th
BASIC ASSIST TORQUE CALCULATION PROCESS
M42
Tb
M44
Tbc
M34
1
M36
1
M38
M60
G
Tcjc
M46
Ta
M48
MANIPULATION SIGNAL OUTPUT PROCESS
MS
M16
MOTOR ANGLE ACQUISITION PROCESS
θm
M18
PINION ANGLE CALCULATION PROCESS
θp
M20
S
M22
S
M24
J
Gp
M26
M14
Trq
Tm
M10
DETECTION VALUE ACQUISITION PROCESS
M12
TORQUE CALCULATION PROCESS
iu
iv
iw

FIG. 4

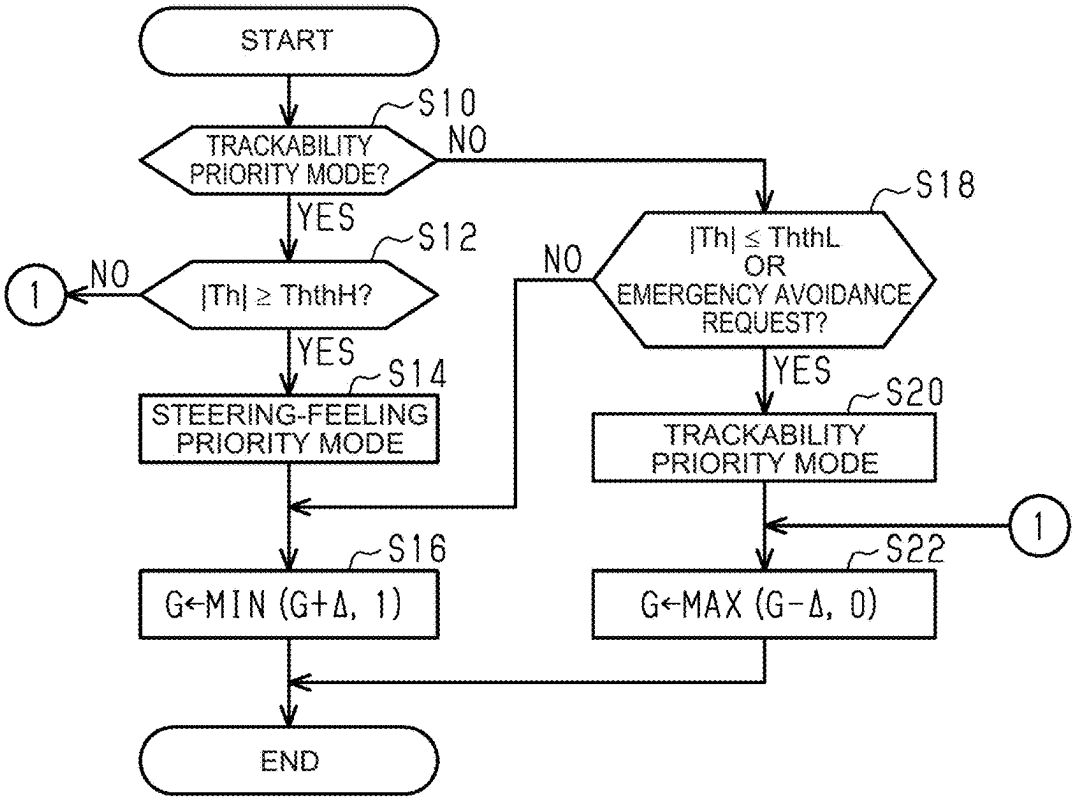

START
S10
TRACKABILITY PRIORITY MODE?
NO
YES
S12
|Th| ≥ ThthH?
NO
1
YES
S14
STEERING-FEELING PRIORITY MODE
S16
G←MIN (G+Δ, 1)
S18
|Th| ≤ ThthL OR EMERGENCY AVOIDANCE REQUEST?
NO
YES
S20
TRACKABILITY PRIORITY MODE
1
S22
G←MAX (G-Δ, 0)
END

FIG. 5

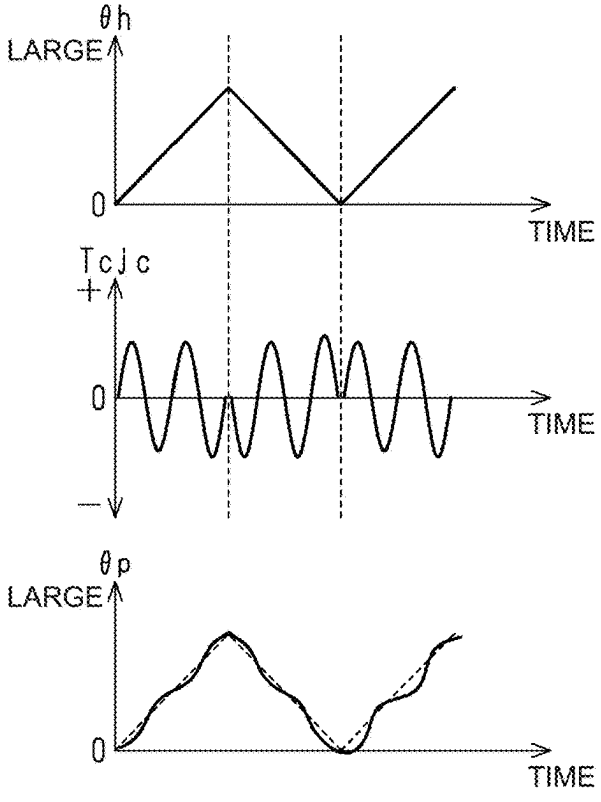

θh
LARGE
0
TIME
Tcjc
+
0
−
TIME
θp
LARGE
0
TIME

FIG. 6

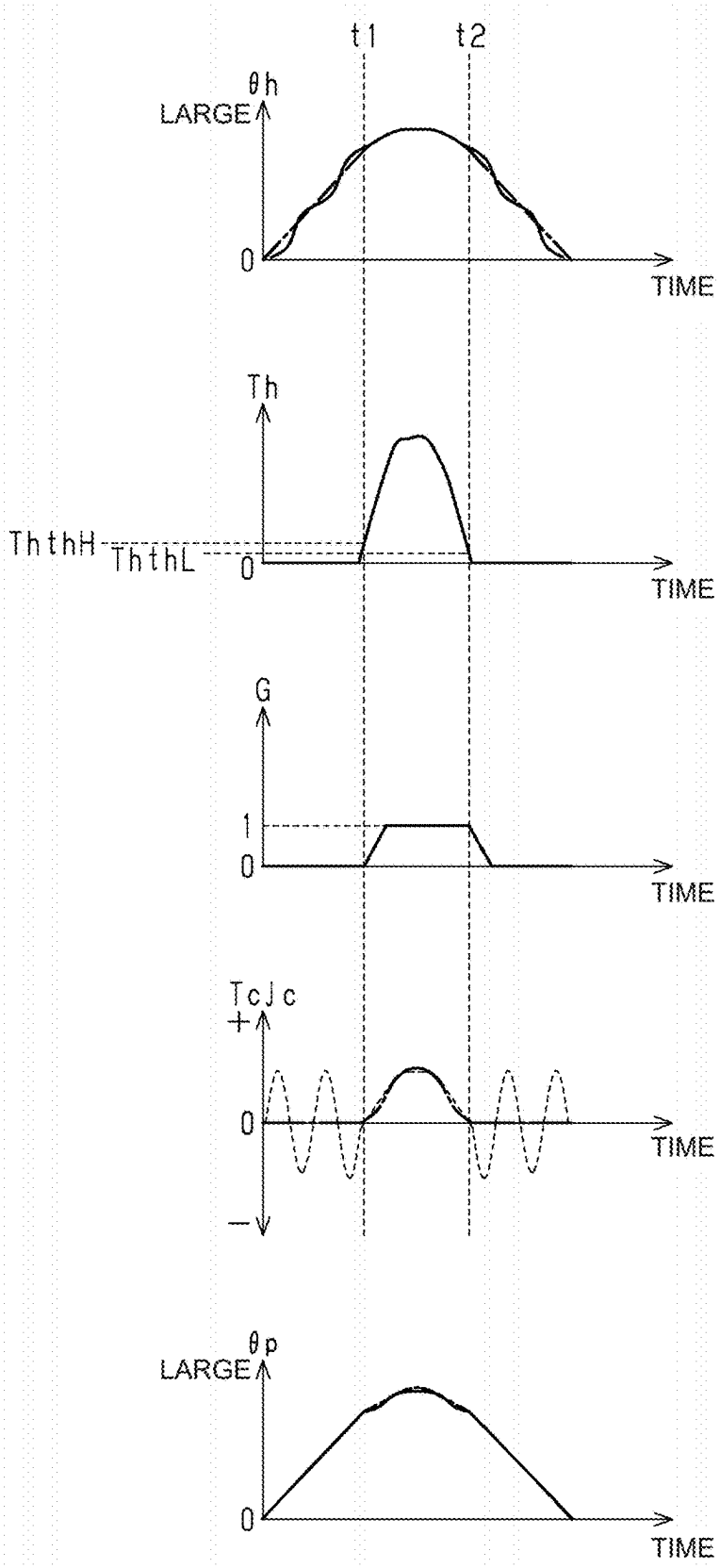
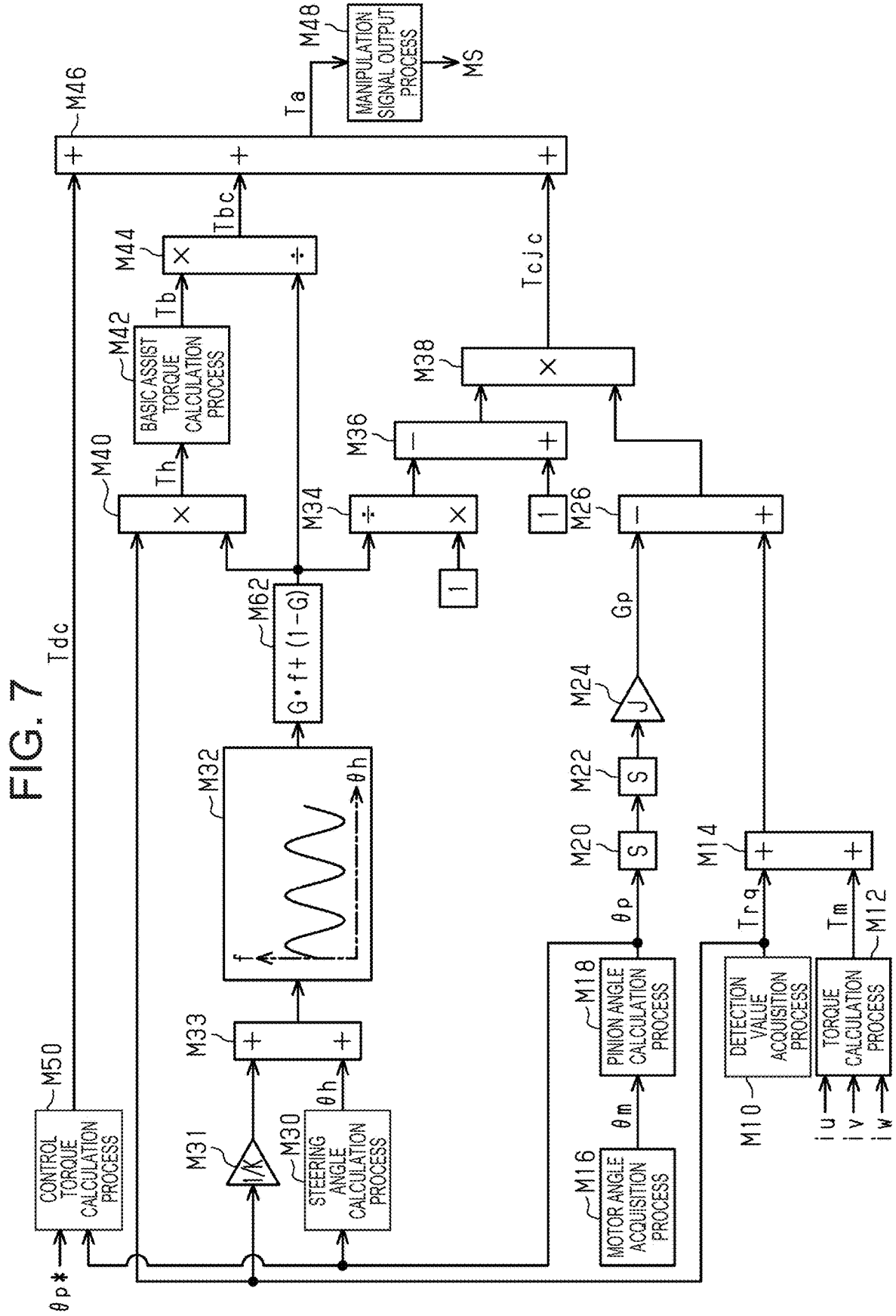

t1
t2
θh
LARGE
0
TIME
Th
ThthH
ThthL
0
TIME
G
1
0
TIME
TcJc
+
0
−
TIME
θp
LARGE
0
TIME

FIG. 7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M32
f
θh
M62
G・f+(1-G)
M34
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θm
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PINION ANGLE CALCULATION PROCESS
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M22
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M10
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Trq
M14
TORQUE CALCULATION PROCESS
Tm
M12
iu
iv
iw

TURNING CONTROL DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to Japanese Patent Application No. 2024-020172 filed on Feb. 14, 2024. The disclosure of the above-identified application, including the specification, drawings, and claims, is incorporated by reference herein in its entirety.

BACKGROUND

1. Technical Field

[0002] The present disclosure relates to a turning control device.

2. Description of Related Art

[0003] For example, Japanese Unexamined Patent Application Publication No. 2003-205846 (JP 2003-205846 A) describes a device that transmits the torque of a steering wheel to a turning wheel through a steering shaft, an intermediate shaft, and a transmitting shaft. The steering shaft and the intermediate shaft, and the intermediate shaft and the transmitting shaft, are each coupled by a universal joint. Further, the device includes a motor that gives a torque to the intermediate shaft.

SUMMARY

[0004] In the case where the universal joint is included as described above, the ratio between a torque that is given to the steering shaft and a torque that is given to the transmitting shaft varies depending on the steering angle. The inventor has studied to give the torque of the motor to a position that is closer to the turning wheel than the universal joint is. In that case, when the torque at the position that is closer to the turning wheel is controlled so as not to vary depending on the steering angle, the torque that is given to the steering shaft varies depending on the steering angle. When the torque that is given to the steering shaft varies depending on the steering angle, a driver can have a feeling of strangeness.

[0005] A turning control device according to a first aspect of the present disclosure controls a turning device. The turning device includes a steering wheel, an input shaft, an intermediate shaft, an output shaft, a first Cardan joint, a second Cardan joint, an assist motor, and a turning wheel. The input shaft is coupled to the steering wheel. The first Cardan joint is a member that couples the input shaft and the intermediate shaft. The second Cardan joint is a member that couples the intermediate shaft and the output shaft. The turning wheel is a member to which a steering torque input to the steering wheel is transmitted through the input shaft, the intermediate shaft, and the output shaft. The assist motor is a motor configured to give a torque to a position that is closer to the turning wheel than the second Cardan joint is. The turning control device includes a processor configured to execute a rudder angle variable acquisition process, an assist torque variable calculation process, a control torque acquisition process, a manipulation process, a variation torque control process, and a restriction process. The rudder angle variable acquisition process is a process of acquiring the value of a steering angle variable. The steering angle variable is a variable indicating a steering angle that is the angle of the steering wheel. The assist torque variable calculation process is a process of calculating the value of an assist torque variable. The assist torque variable is a variable indicating a torque for assisting steering by a driver depending on manipulation of the steering wheel. The control torque acquisition process is a process of acquiring the value of a control torque variable. The control torque variable is a variable indicating a torque for controlling a traveling direction of a vehicle independently from the manipulation of the steering wheel. The manipulation process is a process of manipulating a drive circuit of the assist motor depending on a torque that depends on at least one of the two values, the value of the assist torque variable and the value of the control torque variable. The variation torque control process is a process of varying a torque as an input variable in the manipulation process, depending on the steering angle, based on the value of the steering angle variable as an input variable. The restriction process is a process of restricting the magnitude of variation in the torque as the input variable in the manipulation process depending on the steering angle, to a small side, depending on the priority degree of the value of the control torque variable in the manipulation process.

[0006] In the above configuration, the ratio between the torque at the position that is closer to the turning wheel than the second Cardan joint is and the steering torque varies depending on the value of the steering angle variable. Therefore, when the variation in the steering torque is restrained, the torque at the position that is closer to the turning wheel than the second Cardan joint varies. Therefore, in the above configuration, the torque of the assist motor is varied depending on the steering angle. Thereby, it is possible to restrain the variation in the steering torque.

[0007] However, the variation in the torque of the assist motor can interfere with an intended behavior control of the vehicle with the value of the control torque variable. Hence, in the above configuration, the magnitude of the above variation is restricted to the small side depending on the priority degree of the value of the control torque variable. Thereby, it is possible to achieve a suitable balance between the restraint of the variation in the steering torque and the maintenance of a high controllability with the value of the control torque variable.

[0008] In the turning control device according to the first aspect of the present disclosure, the processor may be configured to execute a steering torque variable acquisition process. The steering torque variable acquisition process may be a process of acquiring the value of a steering torque variable that is a variable indicating the steering torque. The restriction process may include a process of recognizing the priority degree depending on the value of the steering torque variable as an input variable.

[0009] The steering torque is a variable indicating driver's steering intention. Therefore, the value of the steering torque variable is a variable appropriate to determine the priority degrees of the steering by the driver and the steering with the value of the control torque variable. Therefore, in the above configuration, it is possible to appropriately set the priority degrees.

[0010] In the turning control device according to the first aspect of the present disclosure, the restriction process may include a process of recognizing the priority degree of the value of the control torque variable, based on a signal that

determines the priority degree of the value of the control torque variable depending on information about the exterior of the vehicle.

[0011] The information about the exterior of the vehicle can include information indicating whether priority is given to the value of the control torque variable regardless of driver's steering intention. Therefore, in the above configuration, it is possible to appropriately set the priority degree.

[0012] In the turning control device according to the first aspect of the present disclosure, the restriction process may include a process of gradually decreasing the magnitude of the variation to zero, at a time of switching from a state where the priority degree of the value of the control torque variable is lower than the priority degree of the value of the assist torque variable to a state where the priority degree of the value of the control torque variable is higher than the priority degree of the value of the assist torque variable.

[0013] In the above configuration, the magnitude of the variation is gradually decreased at the time of the switching to the state where the priority degree of the value of the control torque variable is higher, and thereby, it is possible to perform the transition to a state where the controllability with the value of the control torque variable is high, while avoiding a sudden change in control state.

[0014] In the turning control device according to the first aspect of the present disclosure, the restriction process may include a process of gradually increasing the magnitude of the variation from zero, at a time of switching from a state where the priority degree of the value of the control torque variable is higher than the priority degree of the value of the assist torque variable to a state where the priority degree of the value of the control torque variable is lower than the priority degree of the value of the assist torque variable.

[0015] In the above configuration, the magnitude of the variation is gradually increased at the time of the switching to the state where the priority degree of the value of the control torque variable is lower. Thereby, it is possible to perform the transition to a state where the variation that is given to the steering wheel is restrained, while avoiding a sudden change in control state.

[0016] In the turning control device according to the first aspect of the present disclosure, the value of the control torque variable may be a torque that is added to the value of the assist torque variable for correcting the steering depending on the manipulation of the steering wheel.

[0017] In the case where the value of the control torque variable is superimposed on the assist torque, the manipulation process can be a process of manipulating the drive circuit in consideration of both torques. However, even in the case where both torques are considered, whether priority should be given to a steering feeling or to the controllability with the value of the control torque variable changes depending on situation. Therefore, the advantage of the restriction of the magnitude of the variation depending on the priority degree is particularly large.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] Features, advantages, and technical and industrial significance of exemplary embodiments of the present disclosure will be described below with reference to the accompanying drawings, in which like signs denote like elements, and wherein:

[0019] FIG. **1** is a diagram showing the configuration of a turning control system according to an embodiment;

[0020] FIG. **2** is a diagram showing the configuration of a first Cardan joint according to the embodiment;

[0021] FIG. **3** is a block diagram showing processes that are executed by a control device according to the embodiment;

[0022] FIG. **4** is a flowchart showing the procedure of a process relevant to the setting of a gain in the processes in FIG. **3**;

[0023] FIG. **5** is a time chart showing an effect of the embodiment;

[0024] FIG. **6** is a time chart showing an effect of the embodiment; and

[0025] FIG. **7** is a block diagram showing processes that are executed by a control device according to a second embodiment.

DETAILED DESCRIPTION OF EMBODIMENTS

System Configuration

[0026] As shown in FIG. **1**, the turning device **10** is a device that turns turning wheels **36** in the cooperation between the steering torque that is input to a steering wheel **12** by a driver and the dynamic power of a turning actuator **40**. The turning device **10** is an electric power steering device. Hereinafter, manipulating the steering wheel **12** in the right direction or the left direction is referred to as "steering".

[0027] The steering wheel **12** is fixed to a column shaft **14**. The column shaft **14** is mechanically coupled to an intermediate shaft **18** through a first Cardan joint **16**. The intermediate shaft **18** has a well-known contractible configuration. Of two end portions of the intermediate shaft **18** in the axial direction of the intermediate shaft **18**, an end portion on the reverse side of an end portion that is coupled to the first Cardan joint **16** is coupled to a pinion shaft **22** through a second Cardan joint **20**.

[0028] The pinion shaft **22** is disposed so as to have a predetermined crossing angle with a rack shaft **30**. A rack-and-pinion mechanism **32** is configured by the engagement between a rack tooth **30***a* formed on the rack shaft **30** and a pinion tooth **22***a* formed on the pinion shaft **22**. Further, tie rods **34** are coupled to both ends of the rack shaft **30**. Distal ends of the tie rods **34** are coupled to unillustrated knuckles to which the turning wheels **36** are secured. By the rack-and-pinion mechanism **32**, the rotation manipulation of the steering wheel **12** is transformed into the displacement action of the rack shaft **30** in the axial direction of the rack shaft **30**. The displacement action in the axial direction is transmitted to the knuckles through the tie rods **34**, and thereby, the turning angle of the turning wheel **36** is changed. The turning angle is the moving angle of a tire that is the turning wheel **36**.

[0029] The turning actuator **40** includes an assist motor **42** that is a drive source, a transmission mechanism **44** that transmits the torque of the assist motor **42**, and a ball screw

mechanism **46**. The ball screw mechanism **46** transforms the torque of the assist motor **42** that is transmitted through the transmission mechanism **44**, into the power for the displacement of the rack shaft **30** in the axial direction. As an example, the assist motor **42** is a three-phase brushless motor. The output voltage of an inverter **60** as a drive circuit is applied to a terminal of the assist motor **42**.

[0030] The control device **50** includes a PU **52** and a storage device **54**. The PU **52** is a software processing device that includes at least one of a CPU, a GPU, and the like. The control device **50** manipulates the inverter **60** for controlling the controlled amount of the turning wheel **36** as a controlled object. For the control of the controlled amount, the control device **50** refers to a rotation angle θ_m of the assist motor **42** that is detected by a rotation angle sensor **70**. Further, the control device **50** refers to electric currents iu, iv, iw that are output by the inverter **60**. The electric currents iu, iv, iw may be detected as voltage drop amounts at shunt resistors provided on respective legs of the inverter **60**. Further, the control device **50** refers to a detection value Trq of a torque sensor **72**. The detection value Trq is a detection value of the torque that is given to the pinion shaft **22**. The torque sensor **72** is a sensor that detects the torque depending on the torsion angle of a well-known torsion bar provided at the pinion shaft **22**.

[0031] A superior ECU **80** is an electronic control device that generates a command that is relevant to the control of the vehicle and that is superior to the control device **50**. The superior ECU **80** refers to a steering angle θ_h that is detected by a rudder angle sensor **82**. The steering angle θ_h is the rotational angle of the steering wheel **12**. In other words, the steering angle θ_h is the rotational angle of the column shaft **14**. The superior ECU **80** executes a process for controlling the traveling direction of the vehicle based on image data acquired by a camera **84** that indicates an image of the forward view of the vehicle.

[0032] The control device **50** and the superior ECU **80** can communicate with each other. Moreover, the control device **50** can receive the steering angle θ_h that is acquired by the superior ECU **80**. The sampling period of the steering angle θ_h is longer than the sampling period of the rotation angle θ_m.

Cardan Joint

[0033] FIG. **2** shows the configuration of the first Cardan joint **16**. The first Cardan joint **16** includes a first yoke **16***a*, a second yoke **16***b*, and a joint cross **16***c*. The joint cross **16***c* has a cross shape. The joint cross **16***c* couples the first yoke **16***a* and the second yoke **16***b* in a mutually rotatable manner. The first yoke **16***a* is fastened to an end portion of the column shaft **14** by a bolt. The first yoke **16***a* may be welded to the end portion of the column shaft **14**. The second yoke **16***b* is fixed to an end portion of the intermediate shaft **18** by welding.

[0034] The configuration of the second Cardan joint **20** is the same as the configuration of the first Cardan joint **16**, and therefore, the description about the configuration of the second Cardan joint **20** is omitted.

Variation in Torque Due to Cardan Joint

[0035] A ratio f(θh) (=Th/Trq) between a steering torque Th that is a torque that is given to the steering wheel **12** and a torque that is given to the pinion shaft **22** has a relation that is expressed as the following Expression (c1).

$$f(\theta h)=\frac{\cos\alpha 1\cdot\cos\alpha 2}{\left(1-\sin^2\alpha 1\cdot\sin^2\theta h\right)\cdot\left[1-\sin^2\alpha 2\{\sin(\arctan(\tan\theta h\cdot\cos\alpha 1))+\phi\}\right]} \quad (c1)$$

[0036] Here, a bend angle α**1** of the first Cardan joint **16**, a bend angle α**2** of the second Cardan joint **20**, and a phase difference ψ are used. The bend angle α**1** of the first Cardan joint **16** is the angle between the axial direction of the column shaft **14** and the axial direction of the intermediate shaft **18**. Further, the bend angle α**2** of the second Cardan joint **20** is the angle between the axial direction of the intermediate shaft **18** and the axial direction of the pinion shaft **22**. The phase difference ψ is "90–ξ+ε". Here, "ξ" is the angle between a plane parallel to both of the axial direction of the column shaft **14** and the axial direction of the intermediate shaft **18** and a plane parallel to both of the axial direction of the intermediate shaft **18** and the axial direction of the pinion shaft **22**. Further, "ε" is the phase difference between the second yoke **16***b* that is of the two yokes of the first Cardan joint **16** and that is on the intermediate shaft **18** side and the yoke that is of the two yokes of the second Cardan joint **20** and that is on the intermediate shaft **18** side. The phase difference indicates a gap in rotational angle around the axial direction of the intermediate shaft **18**.

[0037] According to the above Expression (c1), for example, in the case where the torque that is given to the pinion shaft **22** is constant without depending on the steering angle θh, the steering torque Th can vary depending on the steering angle θh. In the case where the steering torque Th varies depending on the steering angle θh, the driver can have a feeling of strangeness about the manipulation of the steering wheel **12**. A control for coping with this will be described below.

Torque Control for Assist Motor

[0038] FIG. **3** shows processes that are executed by the control device **50**. The processes shown in FIG. **3** are realized when the PU **52** repeatedly executes an assist control program **54***a* stored in the storage device **54**, for example, with a predetermined period.

Manual Steering Process

[0039] First, a process when the superior ECU **80** does not perform steering intervention will be described below. In other words, a manual steering process will be described. A detection value acquisition process M**10** is a process of acquiring the detection value Trq by the torque sensor **72** with a predetermined sampling period.

[0040] A torque calculation process M**12** is a process of calculating a motor torque Tm that is a torque generated in the assist motor **42**, based on the electric currents iu, iv, iw that flow through the assist motor **42**. Actually, the motor torque Tm is a torque resulting from converting the torque of the assist motor **42** into the torque of the pinion shaft **22**.

[0041] An addition process M**14** is a process of adding the detection value Trq and the motor torque Tm. A motor angle

acquisition process M**16** is a process of calculating the rotation angle θm of a rotation shaft of the assist motor **42** with a predetermined sampling period.

[0042] A pinion angle calculation process M**18** is a process of calculating a pinion angle θp that is the rotation angle of the pinion shaft **22**, based on the rotation angle θm as an input variable. A differential operator M**20** is a process of calculating a first-order time-differential value based on the pinion angle θp as an input variable.

[0043] A differential operator M**22** is a process of calculating a first-order time-differential value based on the output value of the differential operator M**20** as an input variable. An inertia term calculation process M**24** is a process of outputting an inertia term Gp that is a value resulting from multiplying the output value of the differential operator M**22** by an inertia coefficient J. The output value of the differential operator M**22** is a second-order time-differential value of the pinion angle θp, and therefore, the output value of the inertia term calculation process M**24** corresponds to the inertia torque of the turning device **10**.

[0044] A subtraction process M**26** is a process of subtracting the output value of the inertia term calculation process M**24** from the output value of the addition process M**14**. A steering angle calculation process M**30** is a process of calculating the steering angle θh based on the pinion angle θp as an input variable. The steering angle calculation process M**30** is a process of calculating the steering angle θh using a mapping that is prescribed by mapping data **54***b* stored in the storage device **54** shown in FIG. **1**. The mapping is a mapping that receives the pinion angle θp as an input and that outputs the steering angle θh. The mapping is prescribed by the following Expression (c2).

$$\theta h = -\arctan\frac{\tan\left[-\arctan\left\{\frac{\tan(\theta p + \arctan(\tan\phi \cdot \cos\alpha 2))}{\cos\alpha 2}\right\} + \phi\right]}{\cos\alpha 1} \tag{c2}$$

[0045] The above expression is derived by applying an expression that prescribes the relation between the rotation angles and bend angles of a pair of the yokes of a Cardan joint, to the first Cardan joint **16** and the second Cardan joint **20**.

[0046] That is, the above expression is derived by using a simultaneous equation including the following expressions (c3) and (c4).

$$\tan\theta 2 = \cos\alpha 1 \cdot \tan\theta h \tag{c3}$$

$$\tan(\theta p') = \cos\alpha 2 \cdot \tan(\theta 2 + \psi) \tag{c4}$$

[0047] The above "θ**2**" is the rotation angle of the intermediate shaft **18**. Further, "θp'" indicates the phase difference of the pinion angle θp from "θh". Specifically, the following Expression (c5) is derived from Expression (c3) and Expression (c4).

$$\theta p' = \arctan(\tan[\arctan\{\tan(\theta h) \cdot \cos(\alpha 1)\} + \psi] \cdot \cos(\alpha 2)) \tag{c5}$$

[0048] Accordingly, the pinion angle θp is expressed as the following Expression (c6).

$$\theta p = \theta p' - \arctan\{\tan(\psi) \cdot \cos(\alpha 2)\} \tag{c6}$$

[0049] The above Expression (c2) is derived by eliminating θp' from Expression (c5) and Expression (c6).

[0050] The mapping data **54***b* includes data about values of the first bend angle α**1**, the second bend angle α**2**, and the phase difference w, and the like. The above Expression (c1) is calculated based on the ratio between a first-order time-differential value of the steering angle θ_h and the first-order time-differential value of the pinion angle θp and an expression for energy conservation. The first-order time-differential value of the steering angle θ_h can be calculated by the time differential of the above Expression (c2)

[0051] A rigidity coefficient multiplication process M**31** is a process of multiplying the detection value Trq by the reciprocal of a rigidity coefficient K. The rigidity coefficient K is a coefficient indicating the torsional rigidity of the torsion bar. A steering angle correction process M**33** is a process of correcting the steering angle θh by multiplying the steering angle θh output by the steering angle calculation process M**30** by the output value of the rigidity coefficient multiplication process M**31**. The steering angle θh determined from the above Expression (c2) deviates from the actual steering angle by the torsional amount of the torsion bar. An amount resulting from multiplying the detection value Trq by the reciprocal of the rigidity coefficient K is an estimated value of the torsional amount of the torsion bar.

[0052] A ratio calculation process M**32** is a process of calculating the ratio f(θh) between the torque of the pinion shaft **22** and the steering torque Th. For example, the ratio f(θh) may be expressed as the above Expression (c1). That is, the ratio f(θh) may be calculated by the PU **52** using Expression (c1), by storing data prescribing the above Expression (c1) in the storage device **54**. Further, for example, the map computation of the ratio f(θh) may be performed by the PU **52**, in a state where map data is previously stored in the storage device **54**. The map data is data in which the steering angle θh is adopted as an input variable and the ratio f(θh) is adopted as an output variable.

[0053] The map data is combination data of discrete values of the input variable and values of the output variable that correspond to the respective values of the input variable. Further, in the map computation, in the case where the value of the input variable coincides with one of the values of the input variable in the map data, the corresponding value of the output variable in the map data may be adopted as the computation result. Further, in the map computation, in the case where the value of the input variable does not coincide with any of the values of the input variable in the map data, a value obtained by the interpolation with a plurality of values of the output variable that is included in the map data may be adopted as the computation result. Alternatively, in the map computation, in the case where the value of the input variable does not coincide with any of the values of the input variable in the map data, the closest value of the plurality of values of the input variable that is included in the map data may be adopted, and the corresponding value of the output variable in the map data may be adopted as the computation result.

[0054] A division process M**34** is a process of calculating the reciprocal of the ratio f(θh). A subtraction process M**36** is a process of subtracting the output value of the division process M**34** from "1". A compensation torque calculation process M**38** is a process of calculating a Cardan joint compensation torque Tcjc by multiplying the output value of the subtraction process M**26** and the output value of the subtraction process M**36**.

[0055] A steering torque calculation process M**40** is a process of calculating the steering torque Th by multiplying the detection value Trq by the ratio f(θh). A basic assist torque calculation process M**42** is a process of calculating a basic assist torque Tb based on the steering torque Th as an input variable. That is, the basic assist torque calculation process M**42** is a process of changing the basic assist torque Tb depending on driver's steering intention indicated by the steering torque Th.

[0056] A variation torque calculation process M**44** is a process of calculating a variation torque Tbc by dividing the basic assist torque Tb by the ratio f(θh). A superimposition process M**46** is a process of calculating an assist torque Ta by adding the variation torque Tbc and the Cardan joint compensation torque Tcjc.

[0057] A manipulation signal output process M**48** is a process of generating and outputting a manipulation signal MS of the inverter **60** for controlling the torque of the assist motor **42** to the assist torque Ta. Actually, the manipulation signal MS is a manipulation signal for each switching element of the inverter **60**.

Case of Steering Intervention

[0058] In FIG. **3**, a process when steering intervention is performed will be described below. A control torque calculation process M**50** is a process of calculating a control torque Tdc based on a target pinion angle θp* and the pinion angle θp as input variables. The target pinion angle θp* is a value that is calculated by the superior ECU **80** for controlling the traveling direction of the vehicle. The control torque Tdc is a manipulated amount in a feedback control in which the pinion angle θp is a controlled amount and the target pinon angle θp* is a target value of the controlled amount.

[0059] A compensation torque restriction process M**60** is a process of restricting the magnitude of the Cardan joint compensation torque Tcjc to a small side. Specifically, the compensation torque restriction process M**60** is a process of correcting the Cardan joint compensation torque Tcjc by multiplying the output value of the compensation torque calculation process M**38** by a gain G.

[0060] An amplitude restriction process M**62** is a process of restricting the amplitude of the ratio f to a small side. Specifically, the amplitude restriction process M**62** is a process of substituting the sum of a value resulting from multiplying the ratio f output by the ratio calculation process M**32** by the gain G and "1−G", in the ratio f.

[0061] FIG. **4** shows the procedure of a process of setting the gain G that is used for the restriction in the compensation torque restriction process M**60** and the amplitude restriction process M**62**. The process shown in FIG. **4** is realized when the PU **52** repeatedly executes a program stored in the storage device **54**, for example, with a predetermined period. Hereinafter, step numbers of processes are expressed as numerals to each of which "S" is added as the initial character.

[0062] In a sequence of processes shown in FIG. **4**, first, the PU **52** determines whether the control mode is a trackability priority mode (S**10**). The trackability priority mode is a mode in which priority is given to the trackability of the control of the traveling direction of the vehicle by the superior ECU **80**, over the steering feeling caused by the manipulation of the steering wheel **12** by the driver. In the case where the PU **52** determines that the control mode is the trackability priority mode (S**10**: YES), the PU **52** determines whether the absolute value of the steering torque Th is larger than or equal to a first threshold ThthH (S**12**). In the case where the PU **52** determines that the absolute value of the steering torque Th is larger than or equal to the first threshold ThthH (S**12**: YES), the PU **52** switches the control mode to a steering-feeling priority mode (S**14**). The steering-feeling priority mode is a mode in which priority is given to the steering feeling caused by the manipulation of the steering wheel **12** by the driver, over the trackability of the control of the traveling direction. Then, the PU **52** substitutes one that is of two values: a value resulting from adding a predetermined positive amount Δ to the gain G and **1** and that is not larger than the other, in the gain G (S**16**).

[0063] On the other hand, in the case where the PU **52** determines that the control mode is not the trackability priority mode (S**10**: NO), the PU **52** determines whether the logical sum of the following condition (A) and condition (B) is true (S**18**).

[0064] Condition (A): A condition that the absolute value of the steering torque Th is smaller than or equal to a second threshold ThthL. The second threshold ThthL is smaller than the first threshold ThthH.

[0065] Condition (B): A condition that there is an emergency avoidance request. The emergency avoidance request is a request to avoid the vehicle from colliding with a physical body at a traveling-directional forward position. The superior ECU **80** monitors whether the vehicle is in a state of colliding with the physical body at the traveling-directional forward position, based on the image data about the traveling-directional forward view that is acquired by the camera **84**. Then, in the case where the superior ECU **80** determines that the vehicle can collide with the physical body at the traveling-directional forward position, the superior ECU **80** determines that there is the emergency avoidance request. The superior ECU **80** outputs a signal indicating that there is the emergency avoidance request, to the control device **50**. In the case where the PU **52** receives the signal from the superior ECU **80**, the PU **52** determines that the condition (B) is satisfied.

[0066] In the case where the PU **52** determines that the above logical sum is false (S**18**: NO), the PU **52** transitions to the process of S**16**. On the other hand, in the case where the PU **52** determines that the above logical sum is true (S**18**: YES), the PU **52** sets the control mode to the trackability priority mode (S**20**). In the case where the PU **52** completes the process in S**20** or makes the negative determination in the process of S**12**, the PU **52** substitutes one that is of two values: a value resulting from subtracting the predetermined amount Δ from the gain G and 0 and that is not smaller than the other, in the gain G (S**22**).

[0067] In the case where the PU **52** completes the process of S**16** or S**22**, the PU **52** ends the sequence of processes shown in FIG. **4** once.

Operation and Effect of Embodiment

[0068] The following Expression (c5) is a motion equation for the pinion shaft **22**.

$$Trq + Tm = Gp + Tp \tag{c5}$$

[0069] Here, the inertia term Gp is an inertia term of the torque of the pinion shaft **22**. Further, a torque Tp is a torque other than the inertia term Gp that is given to the pinion shaft **22**.

[0070] The above Expression (c5) can be expressed as the following Expression (c6).

$$Trq = Gp + Tp - Tm \tag{c6}$$

[0071] When the ratio f(θh) in the above Expression (c1) is used, the steering torque Th can be expressed as the following Expression (c7).

$$Th = f(\theta h) \cdot (Gp + Tp - Tm) \tag{c7}$$

[0072] The motor torque Tm that is the assist torque is expressed as Expression (c8).

$$Tm = Tbc + \{1 - (1/f(\theta h))\} \cdot Tp \tag{c8}$$

[0073] When the above Expression (c8) is substituted in the above Expression (c7), the following Expression (c9) is obtained.

$$Th = Tp + f(\theta h) \cdot (Gp - Tbc) \tag{c9}$$

[0074] When "Tbc=Tb/f(θh)" is substituted in the above Expression (c9), the following Expression (c10) is obtained.

$$Th = Tp - Tb + f(\theta h) \cdot Gp \tag{c10}$$

[0075] In the above Expression (c10), when the term "f(θh). Gp" is ignored, the ratio between the steering torque Th and "Tp−Tb" does not depend on the steering angle θh.

[0076] Therefore, when the variation in the torque Tp depending on the steering angle θh is small, it is possible to restrain the steering torque Th from varying depending on the steering angle θh. Therefore, in the embodiment, the motor torque Tm is set to the sum of the variation torque Tbc and the Cardan joint compensation torque Tcjc. That is, the Cardan joint compensation torque Tcjc is the second term in the right-hand member of the above Expression (c8).

[0077] In this way, the assist torque Ta is set depending on the Cardan joint compensation torque Tcjc and the like, and thereby, it is possible to restrain the steering torque Th from periodically varying depending on the steering angle θh. Therefore, the control makes it possible to restrain the decrease in steering feeling due to the structure of the steering device.

[0078] The control torque Tdc is superimposed on the assist torque Ta. The control torque Tdc is a torque that is requested for causing the vehicle to appropriately travel or avoiding a crisis situation. For example, in the case where the vehicle is about to depart from a lane, the control torque Tdc becomes a value that makes it possible to restrain the vehicle from departing from the lane by the fine adjustment of the steering by the driver. However, the control torque Tdc and the Cardan joint compensation torque Tcjc can interfere with each other. That is, the actual behavior of the vehicle can deviate from a behavior of the vehicle that is intended by the control torque Tdc due to the Cardan joint compensation torque Tcjc.

[0079] Hence, in the case where the control mode switches from the steering-feeling priority more to the trackability priority mode, the PU **52** sets the gain G to zero. Thereby, the Cardan joint compensation torque Tcjc that is input to the superimposition process M**46** by the compensation torque restriction process M**60** is set to zero. Therefore, it is possible to restrain the traveling intended by the superior ECU **80** from being hindered by the Cardan joint compensation torque Tcjc when priority should be given to the traveling control of the vehicle by the superior ECU **80**. Further, when the gain G is set to zero, the ratio f that is input to the steering torque calculation process M**40** and the division process M**34** by the amplitude restriction process M**62** is set to 1. Therefore, the steering torque Th becomes equal to the detection value Trq. In other words, the amplitude of the periodical variation in the detection value Trq depending on the steering angle θh is set to zero.

[0080] FIG. **5** exemplifies the transitions of the steering angle θh, the Cardan joint compensation torque Tcjc, and the pinion angle θp in the steering-feeling priority mode. As shown in FIG. **5**, in the case where the Cardan joint compensation torque Tcjc is periodically varied depending on the steering angle θh, the pinion angle θp varies due to the Cardan joint compensation torque Tcjc as shown by a solid line.

[0081] FIG. **6** exemplifies the change in control mode. In a sequence of processes shown in FIG. **6**, at time t**1**, the absolute value of the steering torque Th becomes larger than or equal to the first threshold ThthH, and thereby, the gain G gradually increases to 1. Further, at time t**2**, the absolute value of the steering torque Th becomes smaller than or equal to the second threshold ThthL, and thereby, the gain G gradually decreases to 0. In the case where the gain G is zero, the Cardan joint compensation torque Tcjc is set to zero, so that the minute variation in the pinion angle θp is restrained.

[0082] With the embodiment, the following operations and effects are further obtained. (1) The PU **52** recognizes the priority degrees of the steering of by the driver and the steering by the control torque Tdc, depending on the steering torque Th. The steering torque Th is a variable indicating driver's steering intention, and therefore, the steering torque Th is a variable appropriate to determine the priority degrees of the steering by the driver and the steering by the control torque Tdc. Therefore, it is possible to appropriately set the priority degrees.

[0083] (2) The PU **52** recognizes the priority degrees of the steering by the driver depending on the steering torque Th and the steering by the control torque Tdc, depending on whether the emergency avoidance request is generated. In the case where the emergency avoidance request is generated, it is thought that a circumstance in which priority is given to the control torque Tdc regardless of driver's steering intention has occurred. Therefore, the PU **52** can appropriately set the priority degrees by considering whether there is the emergency avoidance request.

[0084] (3) In the case where the control mode switches from the steering-feeling priority mode to the trackability priority mode, the PU **52** gradually decreases the gain G to zero. Thereby, it is possible to perform the transition to a state where the controllability with the control torque Tdc becomes high, while avoiding a sudden change in control state.

[0085] (4) In the case where the control mode switches from the trackability priority mode to the steering-feeling priority mode, the PU **52** gradually increases the gain G to 1. Thereby, it is possible to perform the transition to a state where the variation that is given to the steering wheel **12** is restrained, while avoiding a sudden change in control state.

Second Embodiment

[0086] A second embodiment will be described below mainly about differences from the first embodiment, with reference to the drawings.

[0087] FIG. **7** shows processes that are executed by the control device **50** in the embodiment. The processes shown in FIG. **7** are realized when the PU **52** repeatedly executes the assist control program **54***a* stored in the storage device **54**, for example, with a predetermined period. In FIG. **7**, processes corresponding to processes shown in FIG. **3** are denoted by identical reference characters, for convenience purpose.

[0088] As shown in FIG. **7**, in the embodiment, although the amplitude restriction process M**62** is provided, the compensation torque restriction process M**60** is not employed. In this case, when the gain G is set to zero in the trackability priority mode, the output value of the subtraction process M**36** is zero. Therefore, the output value of the compensation torque calculation process M**38** is zero. Accordingly, the Cardan joint compensation torque Tcjc is zero.

Correspondence Relation

[0089] The correspondence relation between matters in the above embodiments and matters described in "SUMMARY" is shown as follows. The column shaft **14** is an example of the input shaft. The pinion shaft **22** is an example of the output shaft. The steering angle calculation process M**30**, the rigidity coefficient multiplication process M**31**, and the steering angle correction process M**33** constitute an example of the rudder angle variable acquisition process. The basic assist torque calculation process M**42** is an example of the assist torque variable calculation process. The control torque calculation process M**50** is an example of the control torque acquisition process. The manipulation signal output process M**48** is an example of the manipulation process. The inverter **60** is an example of the drive circuit. The process of calculating the Cardan joint compensation torque Tcjc and the variation torque Tbc is an example of the variation torque control process. The compensation torque restriction process M**60** and the amplitude restriction process M**62** constitutes an example of the restriction process. S**12** and S**18** constitute an example of the steering torque variable acquisition process. The emergency avoidance request signal is an example of the signal that determines the priority degree of the control torque depending on the information about the exterior of the vehicle. The process of S**22** is an example of the process of the gradual decrease to zero. The process of S**16** is an example of the process of the gradual increase. The addition of the control torque Tdc to the variation torque Tbc is an example of the superimposition process M**46**.

Other Embodiments

[0090] The embodiment can be carried out while being modified as follows. The embodiment and the following modifications can be carried out while being combined with each other as long as there is no technical inconsistency.

Restriction Process

[0091] It is not essential that the restriction process is a process of gradually changing the gain G depending on time. For example, a process of changing the magnitude of the gain G in a range of "0" or more and "1" or less depending on the magnitude of the absolute value of the steering torque Th may be adopted.

[0092] It is not essential that the restriction process is a process of changing the gain G in a stepwise manner. For example, the restriction process is a process of always setting the gain G to one value of the two values, the value "0" and the value "1".

Control Torque Acquisition Process

[0093] It is not essential that the control torque acquisition process is the control torque calculation process M**50**. For example, the superior ECU **80** may output the control torque Tdc to the control device **50**, and the PU **52** may execute a process of receiving the control torque Tdc.

Control Torque

[0094] It is not essential that the control torque Tdc is the torque that is superimposed on the variation torque Tbc. For example, the control torque Tdc may be a torque for causing the vehicle to autonomously travel in a state where the driver does not hold the steering wheel **12**.

Rudder Angle Variable Acquisition Process

[0095] In the above embodiment, the steering angle θh is estimated based on the pinion angle θp as an input variable, but the present disclosure is not limited to this. For example, the displacement amount of the rack shaft **30** in the axial direction of the rack shaft **30** may be used instead of the pinion angle θp.

Basic Assist Torque Calculation Process

[0096] The basic assist torque calculation process M**42** of calculating the basic assist torque Tb that does not depend on the steering angle θh is not essential. For example, a process of directly calculating the variation torque Tbc using the steering torque Th and the steering angle θh as inputs may be adopted. This process constitutes the assist torque variable calculation process and the variation torque restriction process.

First Bend Angle α**1**, Second Bend Angle α**2**

[0097] In the above embodiment, the first bend angle α**1** and the second bend angle α**2** are set to fixed values that are previously determined, but the present disclosure is not limited to this. For example, in the case where the height of

the steering wheel **12** can be adjusted by the rotation of the column shaft **14** around a rotation center OT as shown by two-dot chain lines in FIG. **1**, the first bend angle α**1** and the second bend angle α**2** may be set depending on the rotation amount of the column shaft **14**. The cause of the change in the bend angles α**1**, α**2** is not limited to the change in tilt angle. For example, the cause of the change in the bend angles α**1**, α**2** may be the use of a telescopic function.

Turning Control Device

[0098] The control device **50** is not limited to a device that includes the PU **52** and the storage device **54** and that executes software processing. For example, a dedicated hardware circuit (for example, an ASIC) that executes at least some of the processes that are executed in the above embodiment may be included. That is, the turning control device only needs to include a processing circuit having one configuration of the following (a) to (c). (a) A processing circuit including a processing device that executes all of the above processes in accordance with programs and a program storing device that stores programs, as exemplified by a ROM. (b) A processing circuit including a processing device that executes some of the above processes in accordance with programs, a program storing device, and a dedicated hardware circuit that executes the other processes. (c) A processing circuit including a dedicated hardware circuit that executes all of the above processes. A plurality of software processing circuits each of which a processing device and a program storing device may be provided, and a plurality of dedicated hardware circuits may be provided. That is, the above processes only need to be executed by a processing circuit that includes at least one of a single or a plurality of software processing circuits and a single or a plurality of dedicated hardware circuits.

Turning Device

[0099] The present disclosure is not limited to the configuration in which the rotation shaft of the assist motor **42** and the rack shaft **30** are disposed so as to be parallel to each other. For example, a second rack-and-pinion mechanism may be included separately from the rack-and-pinion mechanism **32**, and the torque of the assist motor **42** may be given through the second rack-and-pinion mechanism.

Others

[0100] It is not essential that the steering angle θh as the input in the ratio calculation process M**32** is the output value of the steering angle correction process M**33**. For example, the steering angle θh output by the steering angle calculation process M**30** may be adopted as the input in the ratio calculation process M**32**.

What is claimed is:

1. A turning control device configured to control a turning device, the turning device including a steering wheel, an input shaft, an intermediate shaft, an output shaft, a first Cardan joint, a second Cardan joint, an assist motor, and a turning wheel, the input shaft being coupled to the steering wheel, the first Cardan joint being a member that couples the input shaft and the intermediate shaft, the second Cardan joint being a member that couples the intermediate shaft and the output shaft, the turning wheel being a member to which a steering torque input to the steering wheel is transmitted through the input shaft, the intermediate shaft, and the output shaft, and the assist motor being a motor configured to give a torque to a position that is closer to the turning wheel than the second Cardan joint is,

the turning control device comprising a processor configured to execute a rudder angle variable acquisition process, an assist torque variable calculation process, a control torque acquisition process, a manipulation process, a variation torque control process, and a restriction process, wherein:

the rudder angle variable acquisition process is a process of acquiring a value of a steering angle variable, the steering angle variable being a variable indicating a steering angle that is an angle of the steering wheel;

the assist torque variable calculation process is a process of calculating a value of an assist torque variable, the assist torque variable being a variable indicating a torque for assisting steering by a driver depending on manipulation of the steering wheel;

the control torque acquisition process is a process of acquiring a value of a control torque variable, the control torque variable being a variable indicating a torque for controlling a traveling direction of a vehicle independently from the manipulation of the steering wheel;

the manipulation process is a process of manipulating a drive circuit of the assist motor depending on a torque that depends on at least one of the two values, the value of the assist torque variable and the value of the control torque variable;

the variation torque control process is a process of varying a torque as an input variable in the manipulation process, depending on the steering angle, based on the value of the steering angle variable as an input variable; and

the restriction process is a process of restricting a magnitude of variation in the torque as the input variable in the manipulation process depending on the steering angle, to a small side, depending on a priority degree of the value of the control torque variable in the manipulation process.

2. The turning control device according to claim **1**, wherein:

the processor is configured to execute a steering torque variable acquisition process, the steering torque variable acquisition process being a process of acquiring a value of a steering torque variable that is a variable indicating the steering torque; and

the restriction process includes a process of recognizing the priority degree depending on the value of the steering torque variable as an input variable.

3. The turning control device according to claim **1**, wherein the restriction process includes a process of recognizing the priority degree of the value of the control torque variable, based on a signal that determines the priority degree of the value of the control torque variable depending on information about an exterior of the vehicle.

4. The turning control device according to claim **1**, wherein the restriction process includes a process of gradually decreasing the magnitude of the variation to zero, at a time of switching from a state where the priority degree of the value of the control torque variable is lower than a priority degree of the value of the assist torque variable to a

state where the priority degree of the value of the control torque variable is higher than the priority degree of the value of the assist torque variable.

5. The turning control device according to claim **1**, wherein the restriction process includes a process of gradually increasing the magnitude of the variation from zero, at a time of switching from a state where the priority degree of the value of the control torque variable is higher than a priority degree of the value of the assist torque variable to a state where the priority degree of the value of the control torque variable is lower than the priority degree of the value of the assist torque variable.

6. The turning control device according to claim **1**, wherein the value of the control torque variable is a torque that is added to the value of the assist torque variable for correcting the steering depending on the manipulation of the steering wheel.

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