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ELECTRIC VEHICLE AND CONTROL DEVICE

Abstract

An electric vehicle includes a storage device storing a database, and processing circuitry. The processing circuitry reads a target vehicle model corresponding to a target virtual vehicle selected by a driver from the database, and calculates a virtual acceleration rate of the target virtual vehicle by using the target vehicle model. When it is determined that the virtual acceleration rate exceeds a realizable acceleration rate of the electric vehicle during an acceleration period of the electric vehicle in which the accelerator pedal is depressed, the processing circuitry performs a correction process of correcting the virtual acceleration rate in such a manner as to reshape, according to an excess amount, changes over time in the virtual acceleration rate. The processing circuitry controls the electric motor in such a manner that an acceleration rate of the electric vehicle becomes the corrected virtual acceleration rate.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to Japanese Patent Application No. 2024-023738 filed on Feb. 20, 2024, incorporated herein by reference in its entirety.

BACKGROUND

1. Technical Field

[0002] The present disclosure relates to an electric vehicle including an electric motor as a drive source, and to a control device of the electric vehicle.

2. Description of Related Art

[0003] An electric motor can be controlled such as to output a desired motor torque, by controlling applied voltage or a field magnet. By utilizing such a fact, a technology is conceived in which various senses of driving are reproduced by an electric vehicle, by appropriately controlling the electric motor of the electric vehicle. For example, Japanese Patent No. 6787507 discloses a technology in which a sense of driving associated with a manual gear change operation on a manual transmission vehicle is reproduced by an electric vehicle in a simulated manner.

SUMMARY

[0004] One of elements that characterize a sense of driving of each vehicle is a feel of acceleration of the vehicle responding to a driving operation. A feel of acceleration of a vehicle is an important point when a driver enjoys driving the vehicle. In particular, tastes in the feel of acceleration of a vehicle vary from driver to driver. In some cases, a driver may want to enjoy feels of acceleration of various vehicles according to his/her moods.

[0005] Accordingly, the inventors of the present disclosure have been considering a technology in which a virtual acceleration rate at a time when a virtual vehicle is driven is calculated by using a vehicle model, and an electric motor is controlled in such a manner that the calculated virtual acceleration rate is realized by an electric vehicle. A vehicle model can be given for each of a plurality of virtual vehicles. Accordingly, according to the technology, feels of acceleration of the plurality of virtual vehicles can be reproduced by a single electric vehicle in a simulated manner.

[0006] However, acceleration rates that can be realized by an electric vehicle naturally have a limit, in connection with a motor torque output characteristic of an electric motor of the electric vehicle. Accordingly, with regard to a virtual vehicle that has an acceleration characteristic exceeding an acceleration capability of the electric vehicle, there arises a situation in which the acceleration characteristic cannot be realized as it is by the electric vehicle. As a result, a problem arises that a feel of acceleration of such a virtual vehicle cannot be reproduced by the electric vehicle. On the other hand, raising the acceleration capability of the electric vehicle to make it possible to realize the acceleration characteristic of such a virtual vehicle unnecessarily increases costs of the electric vehicle.

[0007] The present disclosure provides an electric vehicle and a control device that, with regard to a virtual vehicle that has an acceleration characteristic exceeding an acceleration capability of the electric vehicle, allow a driver to experience an equivalent feel of acceleration to a feel of acceleration of the virtual vehicle.

[0008] An electric vehicle according to a first aspect of the present disclosure includes an electric motor as a drive source, an accelerator pedal, a storage device storing a database, and processing

circuitry. The database is configured to manage a plurality of vehicle models created by modeling a plurality of virtual vehicles that differs in acceleration characteristic responding to a driving operation by a driver. The processing circuitry is configured to read a target vehicle model corresponding to a target virtual vehicle from the database. The target virtual vehicle is selected by the driver from among the plurality of virtual vehicles. The processing circuitry is configured to calculate a virtual acceleration rate of the target virtual vehicle responding to an operation of the accelerator pedal by using the target vehicle model, based on an operation state of the accelerator pedal and a traveling state of the electric vehicle. The processing circuitry is configured to determine whether or not the virtual acceleration rate exceeds a realizable acceleration rate of the electric vehicle during an acceleration period of the electric vehicle in which the accelerator pedal is depressed. The processing circuitry is configured to perform a correction process when it is determined that the virtual acceleration rate exceeds the realizable acceleration rate of the electric vehicle during the acceleration period. The correction process corrects the virtual acceleration rate in such a manner as to reshape, according to an excess amount, changes over time in the virtual acceleration rate during the acceleration period. The processing circuitry is configured to control the electric motor in such a manner that an acceleration rate of the electric vehicle becomes the corrected virtual acceleration rate.

[0009] In the electric vehicle according to the first aspect of the present disclosure, in the correction process, the processing circuitry may be configured to correct the virtual acceleration rate in such a manner that a jerk at a time when the virtual acceleration rate rises becomes larger than the jerk before the correction during the acceleration period.

[0010] In the electric vehicle according to the first aspect of the present disclosure, in the correction process, the processing circuitry may be configured to correct the virtual acceleration rate in such a manner that the virtual acceleration rate temporarily drops before the virtual acceleration rate rises during the acceleration period.

[0011] In the electric vehicle according to the first aspect of the present disclosure, in the correction process, the processing circuitry may be configured to correct the virtual acceleration rate in such a manner that a period before the virtual acceleration rate rises becomes shorter than the period before the correction during the acceleration period.

[0012] In the electric vehicle according to the first aspect of the present disclosure, the processing circuitry may be configured to calculate a target driving force for the electric vehicle such that the acceleration rate of the electric vehicle becomes the virtual acceleration rate. The processing circuitry may be configured to change motor torque output by the electric motor such that the target driving force is applied to the electric vehicle.

[0013] A control device according to a second aspect of the present disclosure is a control device of an electric vehicle including an electric motor as a drive source and an accelerator pedal. The control device includes a storage device storing a database and processing circuitry. The database is configured to manage a plurality of vehicle models created by modeling a plurality of virtual vehicles that differs in acceleration characteristic responding to a driving operation by a driver. The processing circuitry is configured to read a target vehicle model corresponding to a target virtual vehicle from the database. The target virtual vehicle is selected by the driver from among the plurality of virtual vehicles. The processing circuitry is configured to calculate a virtual acceleration rate of the target virtual vehicle responding to an operation of the accelerator pedal by using the target vehicle model, based on an operation state of the accelerator pedal and a traveling state of the electric vehicle. The processing circuitry is configured to determine whether or not the virtual acceleration rate exceeds a realizable acceleration rate of the electric vehicle during an acceleration period of the electric vehicle in which the accelerator pedal is depressed. The processing circuitry is configured to perform a correction process when it is determined that the virtual acceleration rate exceeds the realizable acceleration rate of the electric vehicle during the acceleration period. The correction process corrects the virtual acceleration rate in such a manner as

to reshape, according to an excess amount, changes over time in the virtual acceleration rate during the acceleration period. The processing circuitry is configured to control the electric motor in such a manner that an acceleration rate of the electric vehicle becomes the corrected virtual acceleration rate.

[0014] In the control device according to the second aspect of the present disclosure, in the correction process, the processing circuitry may be configured to correct the virtual acceleration rate in such a manner that a jerk at a time when the virtual acceleration rate rises becomes larger than the jerk before the correction during the acceleration period.

[0015] In the control device according to the second aspect of the present disclosure, in the correction process, the processing circuitry may be configured to correct the virtual acceleration rate in such a manner that the virtual acceleration rate temporarily drops before the virtual acceleration rate rises during the acceleration period.

[0016] In the control device according to the second aspect of the present disclosure, in the correction process, the processing circuitry may be configured to correct the virtual acceleration rate in such a manner that a period before the virtual acceleration rate rises becomes shorter than the period before the correction during the acceleration period.

[0017] According to the present disclosure, when the virtual acceleration rate of the target virtual vehicle exceeds the realizable acceleration rate of the electric vehicle during the acceleration period of the electric vehicle in which the accelerator pedal is depressed, the virtual acceleration rate is corrected in such a manner that changes over time in the virtual acceleration rate during the acceleration period are reshaped according to an excess amount. Then, the electric motor is controlled in such a manner that the acceleration rate of the electric vehicle becomes the corrected virtual acceleration rate. Thus, it is possible to allow a driver to experience an equivalent feel of acceleration to a feel of acceleration of the virtual vehicle that has an acceleration characteristic exceeding an acceleration capability of the electric vehicle.

Description

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 shows a configuration of an electric vehicle according to an embodiment;

[0020] FIG. 2 is a tree diagram showing an example of inputs of selection that an HMI receives in respect of control modes for the electric vehicle according to the embodiment;

[0021] FIG. 3 shows an example of the functional configuration of a control device functioning as a motor control device;

[0022] FIG. 4 shows an example of an acceleration characteristic of the electric vehicle that is realized when the control mode is on-demand mode;

[0023] FIG. 5 shows an example of an acceleration characteristic of the electric vehicle that is usually realized when an acceleration characteristic of a target virtual vehicle exceeds an acceleration capability of the electric vehicle;

[0024] FIG. 6 shows an example of the functional configuration of an on-demand mode driving force calculation section shown in FIG. 3;

[0025] FIG. 7 is a flowchart showing a process flow of processes that are performed by a correction determination section shown in FIG. 6;

[0026] FIG. 8 shows an implementation example of a correction process according to a first specific example, which is performed by a correction section shown in FIG. 6;

[0027] FIG. 9 shows an implementation example of a correction process according to a second

specific example, which is performed by the correction section shown in FIG. 6;
[0028] FIG. 10 shows an implementation example of a correction process according to a third specific example, which is performed by the correction section shown in FIG. 6;
[0029] FIG. 11 is a flowchart showing a process flow of processes that are performed by the on-demand mode driving force calculation section;
[0030] FIG. 12 shows an example of the configuration of a vehicle model; and
[0031] FIG. 13 shows an example of the functional configuration of the control device functioning as a sound control device.

DETAILED DESCRIPTION OF EMBODIMENTS

[0032] Hereinafter, embodiments of the present disclosure are described with reference to the drawings. Note that the same or corresponding parts are denoted by the same signs throughout the drawings, and description thereof is simplified or omitted.

1 Configuration of Power System of Electric Vehicle

[0033] FIG. 1 schematically shows a configuration of an electric vehicle **100** according to an embodiment of the present disclosure. First, a configuration of a power system of the electric vehicle **100** is described with reference to FIG. 1.

[0034] The electric vehicle **100** includes an electric motor (M) **2** as a traction drive source. The electric motor **2** is, for example, a three-phase alternating-current motor. An output shaft **3** of the electric motor **2** is connected to one end of a propeller shaft **5** via a gearing system **4**. The other end of the propeller shaft **5** is connected to a drive shaft **7** in the front of the vehicle via a differential gear **6**.

[0035] The electric vehicle **100** includes drive wheels **8** that are front wheels and trailing wheels **12** that are rear wheels. The drive wheels **8** are provided on both ends of the drive shaft **7**, respectively.

[0036] The electric vehicle **100** includes a battery (BATT) **14** and an inverter (INV) **16**. The battery **14** stores electric energy for driving the electric motor **2**. In other words, the electric vehicle **100** is a battery electric vehicle (BEV) that travels by using electric energy stored in the battery **14**. The inverter **16** is, for example, a voltage inverter. The inverter **16** controls motor torque output by the electric motor **2** through PWM control.

2 Configuration of Control System of Electric Vehicle

[0037] Subsequently, a configuration of a control system of the electric vehicle **100** is described with reference to FIG. 1.

[0038] The electric vehicle **100** includes a vehicle speed sensor **30** for detecting vehicle speed. At least one of undepicted wheel speed sensors provided at the right and left front wheels **8** and the right and left rear wheels **12**, respectively, is used for the vehicle speed sensor **30**. The vehicle speed is one of the traveling states of the electric vehicle **100**. The electric vehicle **100** may further include sensors for detecting other traveling states of the electric vehicle **100**, such as yaw rate, pose, and surrounding environment.

[0039] The electric vehicle **100** includes an accelerator pedal stroke sensor **32**. The accelerator pedal stroke sensor **32** is provided at an accelerator pedal **22** and outputs a signal indicating an operation state of the accelerator pedal **22**. The operation states of the accelerator pedal include, typically, an accelerator operation amount and an accelerator operation speed. Moreover, the electric vehicle **100** includes a brake pedal stroke sensor **34**. The brake pedal stroke sensor **34** is provided at a brake pedal **24** and outputs a signal indicating an operation state of the brake pedal **24**. The operation states of the brake pedal **24** include, typically, a brake operation amount and a brake operation speed.

[0040] Each of the accelerator pedal **22** and the brake pedal **24** is one of driving operation members used to drive the electric vehicle **100**. In addition, the electric vehicle **100** may also include various driving operation members, such as a steering wheel for driving related to steering.

[0041] The electric vehicle **100** includes a travel environment detection sensor **35**. The travel environment detection sensor **35** is a sensor for detecting a travel environment around the electric

vehicle **100**. The travel environment detection sensor **35** is configured by using a camera, a radar, a LiDAR, a global navigation satellite system (GNSS) receiver, or the like.

[0042] The electric vehicle **100** includes a rotation speed sensor **40**. The rotation speed sensor **40** is provided in the electric motor **2** and outputs a signal indicating a rotation speed of the electric motor **2**.

[0043] The electric vehicle **100** includes a battery management system (BMS) **10**. The battery management system **10** is a system that monitors the cell voltage, current, temperature, and the like of the battery **14**. The battery management system **10** has a function of estimating a state of charge (SOC) of the battery **14**.

[0044] The electric vehicle **100** includes a human machine interface (HMI) **20** and an in-vehicle speaker **21** as interfaces with a driver. The HMI **20** presents various information to the driver through display or sound and receives various inputs from the driver. The HMI **20** is configured by using a display (examples: multi-information display, cluster display), a switch, a touch pad, a speakerphone, a touch screen, or the like. For example, the HMI **20** displays various information on the display and receives an input in response to the displayed information from the driver through an operation of the switch. For example, the HMI **20** displays various information on the touch screen and receives an input in response to the displayed information from the driver through a touch operation on the touch screen. The in-vehicle speaker **21** is a sound generator that artificially generates sound in a vehicle cabin. The in-vehicle speaker **21**, in particular, can generate pseudo-engine sound, which will be described later. The in-vehicle speaker **21** may be configured as part of the HMI **20**.

[0045] The electric vehicle **100** includes a control device **101**. The various sensors and equipment to be controlled that are mounted in the electric vehicle **100** are connected to the control device **101** via an in-vehicle network, such as a controller area network (CAN). In addition to the vehicle speed sensor **30**, the accelerator pedal stroke sensor **32**, the brake pedal stroke sensor **34**, and the rotation speed sensor **40**, other various sensors may be mounted in the electric vehicle **100** and connected to the control device **101** via the in-vehicle network.

[0046] The control device **101** generates a control signal related to various control of the electric vehicle **100**, based on a signal acquired from each sensor. The control device **101** is, typically, an electronic control unit (ECU). The control device **101** may be a combination of a plurality of ECUs. The control device **101** includes at least processing circuitry **102** and a storage device **103**.

[0047] The processing circuitry **102** executes various processes. The processing circuitry **102** is configured by using, for example, a general-purpose processor, an application-specific processor, a central processing unit (CPU), a graphics processing unit (GPU), an application-specific integrated circuit (ASIC), a field-programmable gate array (FPGA), an integrated circuit, a conventional circuit, or one or more combinations of any thereof. A processor including a transistor and other circuitry is an example of the processing circuitry **102**. The processing circuitry **102** can also be referred to as circuitry. The circuitry is hardware programmed to implement functions described in the present disclosure, or hardware that executes the functions.

[0048] The storage device **103** stores various information that is necessary for the processing circuitry **102** to execute the processes. The storage device **103** is configured by using, for example, a recording medium such as a random access memory (RAM), a read only memory (ROM), a solid state drive (SSD), or a hard disk drive (HDD). The storage device **103** stores a computer program **104** that is executable by the processing circuitry **102** and various data **105**. The computer program **104** includes a plurality of instructions that describes the processes to be executed by the processing circuitry **102**. The computer program **104** may be recorded on a computer-readable recording medium. The functionality of the control device **101** is implemented through cooperation between the processing circuitry **102** that executes the computer program **104** and the storage device **103**.

[0049] The control device **101** according to the present embodiment has at least two control modes,

namely, ordinary mode and on-demand mode, in respect of control of the electric vehicle **100**.

Control of the electric vehicle **100** to be performed by the control device **101** changes according to a selected control mode. Hereinafter, the control modes for the electric vehicle **100** are described.

3 Control Modes for Electric Vehicle

[0050] As described above, the control modes for the electric vehicle **100** include at least two modes, namely, the ordinary mode and the on-demand mode. The ordinary mode is a control mode in which the electric vehicle **100** is driven as an ordinary BEV. When the ordinary mode is selected, the control device **101** controls the electric vehicle **100** in such a manner that the electric vehicle **100** operates as an ordinary BEV. In contrast, the on-demand mode is a control mode in which a feel of acceleration of a virtual vehicle selected by the driver (hereinafter, referred to as “target virtual vehicle”) among a plurality of virtual vehicles is reproduced by the electric vehicle **100**. When the on-demand mode is selected, the control device **101** controls the electric vehicle **100** in such a manner that the driver can get a feel of acceleration as if the driver drives the target virtual vehicle. Details of various control of the electric vehicle **100** in each of the ordinary mode and the on-demand mode will be described later.

[0051] In the on-demand mode, the plurality of virtual vehicles includes various vehicles that differ in acceleration characteristic responding to a driving operation by the driver. Each virtual vehicle may be intended to represent a real vehicle, or may be an imaginary vehicle that does not exist in actuality. In general, a difference in acceleration characteristic is derived from a difference in configuration of a powertrain from a drive source to drive wheels, or a difference in method of controlling the powertrain. Accordingly, it can also be thought that the plurality of virtual vehicles includes various vehicles that differ in at least one or some of the elements in the powertrain-related configuration or control method.

[0052] A control mode is selected by the driver operating the HMI **20**. The HMI **20** is configured to receive an input of selection of a control mode from the driver. Moreover, in respect of the on-demand mode, the HMI **20** is configured to receive an input of selection of a target virtual vehicle from the driver.

[0053] FIG. **2** is a tree diagram showing an example of inputs of selection that the HMI **20** receives. For example, via display on the display or the touch screen, the HMI **20** receives an input of selection from the driver as follows, according to the tree shown in FIG. **2**.

[0054] First, the HMI **20** displays a setting menu screen on the display or the touch screen, according to an operation by the driver. An option of “control mode” and an option of “target virtual vehicle” are displayed in an initial screen of the setting menu screen. The option of “control mode” is an option for receiving an input of selection of a control mode from the driver. The option of “target virtual vehicle” is an option for receiving an input of selection of a target virtual vehicle from the driver.

[0055] When the option of “control mode” is selected, an option of “ordinary mode” and an option of “on-demand mode” are displayed next in the setting menu screen. When the option of “ordinary mode” is selected, the HMI **20** determines that the control mode for the electric vehicle **100** is the ordinary mode. When the option of “on-demand mode” is selected, the HMI **20** determines that the control mode for the electric vehicle **100** is the on-demand mode. Thus, the HMI **20** receives an input of selection of a control mode from the driver.

[0056] When the option of “on-demand mode” is selected, an option of “CONV” and an option of “HEV” are displayed next in the setting menu screen. Each of the option of “CONV” and the option of “HEV” represents a category of a plurality of virtual vehicles that can be selected in the on-demand mode. CONV is a category indicating conventional internal combustion engine vehicles (conventional vehicles). HEV is a category indicating hybrid electric vehicles. When the option of “CONV” is selected, an option of “virtual vehicle A1”, an option of “virtual vehicle A2”, and an option of “virtual vehicle B1” are displayed next in the setting menu screen. The virtual vehicle A1, the virtual vehicle A2, and the virtual vehicle B1 are virtual vehicles categorized as CONV among

the plurality of selectable virtual vehicles. Similarly, when the option of “HEV” is selected, options of “virtual vehicle C1” and “virtual vehicle C2” are displayed next in the setting menu screen. The virtual vehicle C1 and the virtual vehicle C2 are virtual vehicles categorized as HEV among the plurality of selectable virtual vehicles. When any one of the options is selected, the HMI **20** determines that a corresponding virtual vehicle is the target virtual vehicle. For example, when the option of “virtual vehicle A2” is selected, the HMI **20** determines that the virtual vehicle A2 is the target virtual vehicle. Thus, the HMI **20** receives an input of selection of a target virtual vehicle from the driver.

[0057] In the description above, the categories of the plurality of virtual vehicles are an example, and the category-related options may be changed as appropriate. For example, category-related options may further include an option indicating plugin hybrid electric vehicles or fuel cell electric vehicles. Moreover, for example, category-related options may be options indicating other categories, such as categories related to types of mounted internal combustion engines (examples: supercharged straight-four engine, flat-six engine, V12 engine). Alternatively, when the option of “on-demand mode” is selected, virtual vehicle-related options may be displayed, without displaying category-related options.

[0058] Note that with regard to each option, a name displayed in the setting menu screen may be set as appropriate, with ease of understanding taken into consideration. For example, for each virtual vehicle-related option, a displayed name may be a more concrete name, such as a car model or a product name, from which the driver can easily image the virtual vehicle.

[0059] As described above, the driver can select a control mode by operating the HMI **20**. The control device **101** controls the electric vehicle **100**, according to the selected control mode.

[0060] In respect of control of the electric vehicle **100**, the control device **101** according to the present embodiment functions as at least a motor control device that controls the electric motor **2** according to a driving operation by the driver. Specifically, the control device **101** functions as the motor control device by the processing circuitry **102** executing the computer program **104** for electric motor control stored in the storage device **103**. The electric motor **2** is a drive source of the electric vehicle **100**. Accordingly, it can also be said that the motor control device is a device that performs drive control of the electric vehicle **100**. Hereinafter, control of the electric vehicle **100** by the motor control device is described.

4 Motor Control Device

[0061] FIG. **3** shows an example of the functional configuration of the motor control device **101a**. The motor control device **101a** calculates a target driving force for the electric vehicle **100** according to a driving operation by the driver. The motor control device **101a** controls the electric motor **2** via the inverter **16** in such a manner that the calculated target driving force is applied to the electric vehicle **100**.

[0062] Signals from the HMI **20** and a sensor system **50** are input into the motor control device **101a**. The sensor system **50** includes the vehicle speed sensor **30**, the accelerator pedal stroke sensor **32**, the brake pedal stroke sensor **34**, the travel environment detection sensor **35**, the rotation speed sensor **40**, and the battery management system **10**. The sensor system **50** may include other undepicted sensors. For example, the sensor system **50** may include a steering angle sensor for detecting the steering angle of the steering wheel, a yaw rate sensor for detecting the yaw rate of the electric vehicle **100**, an inertial measurement unit (IMU) for detecting the pose of the electric vehicle **100**, a sensor (examples: camera, radar, LiDAR) for detecting a surrounding environment around the electric vehicle **100**, and the like.

[0063] The signals input from the HMI **20** into the motor control device **101a** include a signal indicating a control mode selected by the driver and a signal indicating a target virtual vehicle selected by the driver. The signals input from the sensor system **50** into the motor control device **101a** include a signal indicating a vehicle speed of the electric vehicle **100**, a signal indicating the operation state of the accelerator pedal **22**, a signal indicating the operation state of the brake pedal

24, a signal indicating a travel environment around the electric vehicle **100**, a signal indicating a rotation speed of the electric motor **2**, and a signal indicating a state (examples: cell voltage, current, temperature, SOC) of the battery **14**.

[0064] The motor control device **101a** includes, as functional blocks, a mode information acquisition section **110**, an on-demand mode driving force calculation section **120**, an ordinary mode driving force calculation section **130**, a target driving force switching section **140**, and an electric motor control section **150**. The functional blocks are implemented by the processing circuitry **102** that executes the computer program **104** and the storage device **103** cooperating.

[0065] The mode information acquisition section **110** receives a signal from the HMI **20** and acquires information about which one of the ordinary mode and the on-demand mode is selected. The mode information acquisition section **110** acquires information on a target virtual vehicle selected by the driver. The mode information acquisition section **110** transmits information on the selected control mode to the target driving force switching section **140**. The mode information acquisition section **110** transmits information on the selected target virtual vehicle to the on-demand mode driving force calculation section **120**.

[0066] The on-demand mode driving force calculation section **120** acquires the information on the target virtual vehicle selected by the driver from the mode information acquisition section **110**. The on-demand mode driving force calculation section **120** calculates a target driving force in the on-demand mode, based on signals from the sensor system **50**. In other words, the on-demand mode driving force calculation section **120** calculates a target driving force for reproducing, with the electric vehicle **100**, a feel of acceleration of the target virtual vehicle responding to a driving operation by the driver. Details of processes that are executed by the on-demand mode driving force calculation section **120** will be described later.

[0067] The ordinary mode driving force calculation section **130** calculates a target driving force in the ordinary mode, based on signals from the sensor system **50**. In other words, the ordinary mode driving force calculation section **130** calculates a target driving force for causing the electric vehicle **100** to operate as an ordinary BEV. For example, the ordinary mode driving force calculation section **130** calculates the target driving force by using a map that has the accelerator operation amount of the accelerator pedal **22** and the rotation speed of the electric motor **2** as parameters. The ordinary mode driving force calculation section **130** may be configured to calculate the target driving force by further using the brake operation amount of the brake pedal **24** and the SOC of the battery **14** for parameters. However, in the present embodiment, processes that are executed by the ordinary mode driving force calculation section **130** are not particularly limited. For the processes that are executed by the ordinary mode driving force calculation section **130**, any other preferable publicly known technology may be applied.

[0068] The target driving force switching section **140** switches the target driving force for the electric vehicle **100** to be used to control the electric motor **2**, depending on a selected control mode. The target driving force switching section **140** acquires the information on the selected control mode from the mode information acquisition section **110**. When the on-demand mode is selected, the target driving force switching section **140** transmits, as the target driving force for the electric vehicle **100**, the target driving force calculated by the on-demand mode driving force calculation section **120** to the electric motor control section **150**. When the ordinary mode is selected, the target driving force switching section **140** transmits, as the target driving force for the electric vehicle **100**, the target driving force calculated by the ordinary mode driving force calculation section **130** to the electric motor control section **150**.

[0069] Note that the ordinary mode driving force calculation section **130** may be configured not to execute the processes when the on-demand mode is selected. Similarly, the on-demand mode driving force calculation section **120** may be configured not to execute the processes when the ordinary mode is selected.

[0070] The target driving force for the electric vehicle **100** is input into the electric motor control

section **150** via the target driving force switching section **140**. In other words, when the on-demand mode is selected, the target driving force calculated by the on-demand mode driving force calculation section **120** is input into the electric motor control section **150**. When the ordinary mode is selected, the target driving force calculated by the ordinary mode driving force calculation section **130** is input into the electric motor control section **150**. The electric motor control section **150** changes motor torque to be output by the electric motor **2** such that the input target driving force is applied to the electric vehicle **100**. More specifically, the electric motor control section **150** generates a control signal for the inverter **16** according to the input target driving force. The electric motor control section **150** changes the motor torque to be output by the electric motor **2** through PWM control by the inverter **16**.

[0071] Thus, the motor control device **101a** controls the electric motor **2** in such a manner that a target driving force according to a control mode is applied to the electric vehicle **100**. Accordingly, according to the motor control device **101a**, the acceleration characteristic of the electric vehicle **100**, when the on-demand mode is selected, is an acceleration characteristic that simulates the acceleration characteristic of a target virtual vehicle selected by the driver. The acceleration characteristic of the electric vehicle **100**, when the ordinary mode is selected, is the acceleration characteristic of an ordinary BEV.

[0072] FIG. **4** shows an example of the acceleration characteristic VAC of the electric vehicle **100** when the on-demand mode is selected. For comparison, the acceleration characteristic of an ordinary BEV (dash-dotted line) is shown in FIG. **4**. When the on-demand mode is selected, the acceleration characteristic VAC of the electric vehicle **100** varies as the target virtual vehicle is changed, to draw various patterns according to target virtual vehicles. The reason is that the target driving force calculated in the on-demand mode changes according to a target virtual vehicle selected by the driver. As a result, in the on-demand mode, the driver can enjoy feels of acceleration of various virtual vehicles with the electric vehicle **100**.

[0073] Hereinafter, the calculation of the target driving force in the on-demand mode, that is, the processes that are executed by the on-demand mode driving force calculation section **120** are described in detail.

4.1 Calculation of Target Driving Force in On-Demand Mode

[0074] The on-demand mode driving force calculation section **120** calculates the target driving force in such a manner that a feel of acceleration of a target virtual vehicle responding to a driving operation by the driver is reproduced by the electric vehicle **100**. The on-demand mode driving force calculation section **120**, in particular, adopts a scheme (hereinafter, referred to as “virtual acceleration rate-based scheme”) in which a virtual acceleration rate at a time when the target virtual vehicle is driven is calculated (simulated) by using a vehicle model of the target virtual vehicle (hereinafter, referred to as “target vehicle model”), and the target driving force is calculated in such a manner that the acceleration rate of the electric vehicle **100** becomes the virtual acceleration rate.

[0075] Incidentally, the acceleration rates that can be realized by the electric vehicle **100**, that is, the acceleration capability of the electric vehicle **100** naturally has a limit in connection with a motor torque output characteristic of the electric motor **2**. The acceleration capability of the electric vehicle **100**, in particular, is equivalent to the acceleration characteristic of an ordinary BEV. In other words, the acceleration characteristic that can be realized by the electric vehicle **100** comes within the scope of the acceleration characteristic of an ordinary BEV.

[0076] Accordingly, in the virtual acceleration rate-based scheme, there arises a situation in which the acceleration characteristic of a target virtual vehicle cannot be realized as it is by the electric vehicle **100** when the acceleration characteristic of the target virtual vehicle exceeds the acceleration capability of the electric vehicle **100**. FIG. **5** shows an example of the acceleration characteristic VAC of the electric vehicle **100** that is realized when the acceleration characteristic of a target virtual vehicle exceeds the acceleration capability of the electric vehicle **100**. In the

example shown in FIG. 5, the acceleration characteristic VAC of the electric vehicle **100** cannot exactly replicate the acceleration characteristic of the target virtual vehicle (dashed line) due to the limit imposed by the acceleration capability of the electric vehicle **100** (dash-dotted line). Accordingly, in such a case, there is a possibility that an acceleration rate realized by the electric vehicle **100** in response to an operation of the accelerator pedal **22** is smaller than a virtual acceleration rate of the target virtual vehicle to be realized.

[0077] On the other hand, a feel of acceleration that the driver has when accelerating the electric vehicle **100** varies not only with the realized acceleration rate but also with the shape of a graphical representation of changes over time in acceleration rate after the accelerator pedal **22** is depressed. The feel of acceleration that the driver has can be made stronger compared to the realized acceleration rate by appropriately reshaping the changes over time in acceleration rate, based on such a cognitive characteristic of a driver about a feel of acceleration. For example, the larger a jerk is made at a time when the acceleration rate increases, the stronger the feel of acceleration the driver has.

[0078] Based on the point of view as described above, the on-demand mode driving force calculation section **120** according to the present embodiment is configured to allow the driver to experience an equivalent feel of acceleration to a feel of acceleration of a target virtual vehicle even when the acceleration characteristic of the target virtual vehicle exceeds the acceleration capability of the electric vehicle **100**. In other words, the on-demand mode driving force calculation section **120** reshapes changes over time in realized acceleration rate in such a manner that the driver has a stronger feel of acceleration compared to a difference between the acceleration rate realized by the electric vehicle **100** and the virtual acceleration rate of the target virtual vehicle to be realized.

[0079] FIG. 6 shows an example of the functional configuration of the on-demand mode driving force calculation section **120**. The on-demand mode driving force calculation section **120** includes, as functional blocks, a virtual acceleration rate calculation section **121**, a travel scene determination section **122**, a correction determination section **123**, a correction section **124**, and a target driving force calculation section **125**. The on-demand mode driving force calculation section **120** is configured to be able to access a vehicle model database **D10**.

[0080] The vehicle model database **D10** is a database that manages a plurality of vehicle models **200** created by modeling a plurality of virtual vehicles. The vehicle model database **D10** may be implemented as the data **105** stored in the storage device **103**. A new vehicle model **200** may be downloaded into the vehicle model database **D10** as needed. In the example shown in FIG. 6, the vehicle model database **D10** manages three vehicle models **200-A**, **200-B**, and **200-C**. Each vehicle model **200** is a model that receives an operation state AS of the accelerator pedal **22** and a traveling state RS of the electric vehicle **100** as inputs and simulates a behavior of the virtual vehicle responding to a driving operation by the driver. Each vehicle model **200** is configured to be able to simulate at least a driving force that is applied to the virtual vehicle in response to a driving operation, particularly an operation of the accelerator pedal **22**, and an acceleration or deceleration behavior of the virtual vehicle as a result of action of the driving force. A result of simulating the acceleration or deceleration behavior of the virtual vehicle by each vehicle model **200** includes a virtual acceleration rate of the virtual vehicle. In other words, each vehicle model **200** is configured to be able to calculate a virtual acceleration rate of the virtual vehicle responding to a driving operation by the driver.

[0081] Typically, each vehicle model **200** includes a control model that simulates a control system related to the powertrain of the virtual vehicle, and a plant model that simulates an acceleration or deceleration behavior of the virtual vehicle responding to a control signal from the control model. In such a case, the plant model includes a powertrain model that operates based on the control signal from the control model, and a model for simulating a behavior of the virtual vehicle as a result of action of virtual driving force output by the powertrain model. An example of the configuration of a vehicle model **200** will be described later.

[0082] Each vehicle model **200** has a parameter **201** related to the behavior of the virtual vehicle in simulation. Examples of the parameter **201** include vehicle weight, tire diameter, each gear ratio, engine maximum torque, engine torque responsiveness, gear change timing, and the like. The content of the parameter **201** may differ from vehicle model **200** to vehicle model **200**. Each vehicle model **200**, in combination with a set value of the parameter **201**, represents a model of one virtual vehicle. For example, each virtual vehicle corresponds to a combination of a vehicle model **200** and a set value of the parameter **201**, as shown in a table below. As shown in the table, the same vehicle models **200** may correspond to different virtual vehicles. Examples of such a case include a case in which powertrain systems are of the same type and the respective virtual vehicles can be rendered by changing the set value of the parameter **201**.

TABLE-US-00001

TABLE 1	Virtual vehicle	Vehicle model	Parameter	Virtual vehicle
A1	200-A	Set value A1	Virtual vehicle A2	200-A
Set value A2	Virtual vehicle B1	200-B	Set value B1	Virtual vehicle C1
200-C	Set value C1	Virtual vehicle C2	200-C	Set value C2

[0083] The virtual acceleration rate calculation section **121** acquires information on a target virtual vehicle STV selected by the driver from the mode information acquisition section **110**. The virtual acceleration rate calculation section **121** refers to the vehicle model database **D10** and reads a vehicle model **200** (target vehicle model) corresponding to the target virtual vehicle STV. In the example shown in FIG. 6, a case is shown in which the virtual acceleration rate calculation section **121** reads the vehicle model **200-B**. Further, the virtual acceleration rate calculation section **121** sets the parameter **201** of the read vehicle model **200** according to the target virtual vehicle STV. For example, when the target virtual vehicle STV is “virtual vehicle B1” in the table above, the virtual acceleration rate calculation section **121** sets a parameter **201-B** of the vehicle model **200-B** to a set value B1.

[0084] The virtual acceleration rate calculation section **121** calculates a virtual acceleration rate VG of the target virtual vehicle STV responding to an operation of the accelerator pedal **22**, by using the read target vehicle model. More specifically, the virtual acceleration rate calculation section **121** receives signals from the sensor system **50**, and acquires information on the operation state AS of the accelerator pedal **22** (example: the accelerator operation amount) and information on the traveling state RS of the electric vehicle **100** (example: a vehicle speed) to be used for inputs into the target vehicle model. In addition, the virtual acceleration rate calculation section **121** may acquire information on the operation state of the brake pedal **24**, a steering angle of the steering wheel, a yaw rate of the electric vehicle **100**, and the like, depending on the configuration of the target vehicle model. The virtual acceleration rate calculation section **121** inputs the acquired information into the target vehicle model. The virtual acceleration rate calculation section **121** calculates the virtual acceleration rate VG of the target virtual vehicle STV by simulating an acceleration or deceleration behavior of the target virtual vehicle STV by using the target vehicle model. The virtual acceleration rate VG calculated by the virtual acceleration rate calculation section **121** is transmitted to the correction section **124**.

[0085] The travel scene determination section **122** acquires travel environment information TEI from the sensor system **50**. The travel environment information TEI indicates information on a travel environment around the electric vehicle **100**. The travel environment information TEI is, typically, information detected by the travel environment detection sensor **35**. The travel environment information TEI may include map information around the electric vehicle **100**, road traffic information, road shape information, and the like. The travel scene determination section **122** recognizes at least a travel environment in front of the electric vehicle **100**, based on the travel environment information TEI. For example, the travel scene determination section **122** recognizes a situation of another vehicle in front, the curvature and the road width of a road extending frontward, the state of a traffic signal ahead, and the like.

[0086] Further, the travel scene determination section **122** determines a travel scene related to acceleration of the electric vehicle **100**, based on the recognized travel environment. For example,

the travel scene determination section **122** determines the travel scene for the electric vehicle **100**, as to whether “a vehicle exists or not in front”, “the road is a sharp curve or a straight road”, “the road width is narrow or wide”, “a traffic signal ahead is red or green”, or the like.

[0087] The travel scene determination section **122** sets a scene determination flag SF to one or zero, according to the determined travel scene. More specifically, the travel scene determination section **122** sets the scene determination flag SF to one when the determined travel scene is expected to cause the driver to continue accelerating the electric vehicle **100** for a certain period. For example, the travel scene determination section **122** sets the scene determination flag SF to one when the determined travel scene is “no vehicle exists in front”, “a straight road”, “the road width is wide”, “a traffic signal ahead is green”, or the like. The travel scene determination section **122** sets the scene determination flag to zero when the determined travel scene is “a vehicle exists in front”, “a sharp curve”, “the road width is narrow”, “a traffic signal ahead is red”, or the like. The scene determination flag SF indicates whether or not it is preferable for the correction section **124** to correct the virtual acceleration rate VG in respect of the travel scene. The scene determination flag SF set by the travel scene determination section **122** is transmitted to the correction determination section **123**.

[0088] The correction determination section **123** determines whether or not to perform correction of the virtual acceleration rate VG by the correction section **124**, which will be described later, when the driver accelerates the electric vehicle **100** by depressing the accelerator pedal **22**.

[0089] FIG. **7** is a flowchart showing a process flow of processes that are executed by the correction determination section **123**.

[0090] In step **S100**, the correction determination section **123** acquires the information on the target virtual vehicle STV from the mode information acquisition section **110**. The correction determination section **123** acquires, from the sensor system **50**, the information on the operation state AS of the accelerator pedal **22** and the information on the traveling state RS of the electric vehicle **100**. The correction determination section **123** acquires the scene determination flag SF from the travel scene determination section **122**.

[0091] The correction determination section **123** manages an acceleration characteristic of each of a plurality of virtual vehicles that are selectable in the on-demand mode. The correction determination section **123** can refer to the acceleration characteristic of the target virtual vehicle STV, based on the information on the target virtual vehicle STV acquired from the mode information acquisition section **110**. Moreover, the correction determination section **123** manages an acceleration characteristic of the electric vehicle **100** as an ordinary BEV (acceleration capability of the electric vehicle **100**).

[0092] In step **S110**, the correction determination section **123** determines, from the operation state AS, whether or not the accelerator pedal **22** is depressed. For example, the correction determination section **123** determines that the accelerator pedal **22** is depressed when the accelerator operation amount and the amount of a change in accelerator operation amount are each equal to or more than predetermined threshold values.

[0093] When it is determined that the accelerator pedal **22** is depressed (step **S110**; Yes), the process moves to step **S120**. When it is determined that the accelerator pedal is not depressed (step **S110**; No), the correction determination section **123** determines not to perform correction (step **S150**), and terminates the processes.

[0094] In step **S120**, the correction determination section **123** determines whether or not the scene determination flag is one. When the scene determination flag is one (step **S120**; Yes), the process moves to step **S130**. When the scene determination flag is zero (step **S120**; No), the correction determination section **123** determines not to perform correction (step **S150**), and terminates the processes.

[0095] When the scene determination flag is zero, it is expected that even if the accelerator pedal **22** is depressed, the driver immediately undoes the operation of the accelerator pedal **22** in an

attempt to stop accelerating the electric vehicle **100**. The correction determination section **123** prevents the correction section **124** from performing correction of the virtual acceleration rate VG in such a case, through the process according to step **S120**. Thus, it is possible to restrain drivability from lowering due to correction of the virtual acceleration rate VG being unnecessarily performed. [0096] In step **S130**, the correction determination section **123** determines whether or not the virtual acceleration rate VG exceeds an acceleration rate (realizable acceleration rate) that can be realized by the electric vehicle **100** during an acceleration period in which the accelerator pedal **22** is depressed and the electric vehicle **100** accelerates. In other words, the correction determination section **123** determines whether or not an acceleration rate that is realized by the electric vehicle **100** in response to an operation of the accelerator pedal **22** is smaller than the to-be-realized virtual acceleration rate VG during the acceleration period.

[0097] The correction determination section **123** can acquire the realizable acceleration rate based on an accelerator operation amount and a vehicle speed by referring to the acceleration characteristic as an ordinary BEV. Moreover, by referring to the acceleration characteristic of the target virtual vehicle STV, the correction determination section **123** can determine, based on the accelerator operation amount and the vehicle speed, whether or not the virtual acceleration rate VG exceeds the realizable acceleration rate during the acceleration period.

[0098] When the virtual acceleration rate VG exceeds the realizable acceleration rate during the acceleration period (step **S130**; Yes), the correction determination section **123** determines to perform correction (step **S140**), and terminates the processes. When the virtual acceleration rate VG does not exceed the realizable acceleration rate during the acceleration period (step **S130**; No), the correction determination section **123** determines not to perform correction (step **S150**), and terminates the processes.

[0099] As described above, the correction determination section **123** executes the processes and determines whether or not to perform correction of the virtual acceleration rate VG by the correction section **124**. FIG. **6** is referred to again. The correction determination section **123** transmits a determination result JR to the correction section **124**. The determination result JR includes information on whether or not to perform correction. When it is determined to perform correction, the determination result JR further includes information on an excess amount by which the virtual acceleration rate VG exceeds the realizable acceleration rate during the acceleration period. The excess amount represents a difference between the acceleration rate that is realized by the electric vehicle **100** in response to the operation of the accelerator pedal **22** and the virtual acceleration rate VG.

[0100] The correction section **124** acquires the virtual acceleration rate VG from the virtual acceleration rate calculation section **121**. In response to the determination result JR indicating to perform correction, the correction section **124** executes a correction process of correcting the virtual acceleration rate VG. In the correction process, the correction section **124** performs correction of the virtual acceleration rate VG in such a manner as to reshape changes over time in virtual acceleration rate VG during the acceleration period, according to the excess amount indicated by the determination result JR. The correction section **124** transmits, to the target driving force calculation section **125**, a virtual acceleration rate CVG corrected as a result of the correction process being executed.

[0101] The correction process is executed in such a manner that a feel of acceleration that the driver has is made stronger to compensate for the excess amount, by reshaping changes over time in virtual acceleration rate VG during the acceleration period. For such a correction process, the following first to third specific examples can be adopted.

[0102] The first specific example of the correction process is to correct the virtual acceleration rate VG in such a manner that a jerk at a time when the virtual acceleration rate increases is made larger than before correction during the acceleration period. Such correction uses the cognitive characteristic of a driver that the larger a jerk is made at a time when the acceleration rate increases,

the stronger the feel of acceleration the driver has.

[0103] FIG. 8 shows an implementation example of the correction process according to the first specific example. FIG. 8 shows changes over time in accelerator operation amount, virtual acceleration rate VG, and corrected virtual acceleration rate CVG. In the example shown in FIG. 8, the accelerator pedal 22 is depressed during a period between time t1 and time t2. The virtual acceleration rate VG starts rising at time t3 and exceeds the realizable acceleration rate to reach a value corresponding to the accelerator operation amount. In contrast to such a virtual acceleration rate VG, the corrected virtual acceleration rate CVG does not exceed the realizable acceleration rate, but on the other hand, a jerk is larger at a time when the corrected virtual acceleration rate CVG rises. The correction process according to the first specific example corrects the virtual acceleration rate VG as shown in FIG. 8 and calculates the corrected virtual acceleration rate CVG. The correction process according to the first specific example may be configured to determine an extent to which the jerk is made larger according to the excess amount, in order to compensate for the excess amount. As described above, through the correction process according to the first specific example, the corrected virtual acceleration rate CVG realizes an equivalent feel of acceleration to a feel of acceleration realized by the virtual acceleration rate VG before correction.

[0104] The second specific example of the correction process is to correct the virtual acceleration rate VG in such a manner that the virtual acceleration rate temporarily drops before rising during the acceleration period. Such correction uses the cognitive characteristic of a driver that the larger the amount of a change in acceleration rate is, the stronger the feel of acceleration the driver has.

[0105] FIG. 9 shows an implementation example of the correction process according to the second specific example. In FIG. 9, changes over time in accelerator operation amount and virtual acceleration rate VG are similar to those in the case shown in FIG. 8. The corrected virtual acceleration rate CVG shown in FIG. 9, in contrast to the virtual acceleration rate VG, does not exceed the realizable acceleration rate but, on the other hand, temporarily drops before rising (during a period between time t2 and time t3). The correction process according to the second specific example corrects the virtual acceleration rate VG as shown in FIG. 9 and calculates the corrected virtual acceleration rate CVG. The correction process according to the second specific example may be configured to determine an extent to which the virtual acceleration rate is decreased according to the excess amount, in order to compensate for the excess amount. As described above, through the correction process according to the second specific example, the corrected virtual acceleration rate CVG realizes an equivalent feel of acceleration to a feel of acceleration realized by the virtual acceleration rate VG before correction.

[0106] The third specific example of the correction process is to correct the virtual acceleration rate VG in such a manner that a period before the virtual acceleration rate rises is made shorter than before correction during the acceleration period. Such correction uses the cognitive characteristic of a driver that the earlier the acceleration rate starts rising, the stronger feel of acceleration the driver has.

[0107] FIG. 10 shows an implementation example of the correction process according to the third specific example. In FIG. 10, changes over time in accelerator operation amount and virtual acceleration rate VG are similar to those in the case shown in FIG. 8. The corrected virtual acceleration rate CVG shown in FIG. 10, in contrast to the virtual acceleration rate VG, does not exceed the realizable acceleration rate but, on the other hand, has a shorter period before the corrected virtual acceleration rate CVG rises. The correction process according to the third specific example corrects the virtual acceleration rate VG as shown in FIG. 10 and calculates the corrected virtual acceleration rate CVG. The correction process according to the third specific example may be configured to determine a period of time before the virtual acceleration rate rises according to the excess amount, in order to compensate for the excess amount. As described above, through the correction process according to the third specific example, the corrected virtual acceleration rate CVG realizes an equivalent feel of acceleration to a feel of acceleration realized by the virtual

acceleration rate VG before correction.

[0108] The first to third specific examples may be combined. For example, a correction process may be executed by combining the second specific example and the third specific example. In such a case, the correction process may be configured to determine each of an extent to which the virtual acceleration rate is decreased and a period of time before the virtual acceleration rate rises according to the excess amount.

[0109] As described above, the correction section **124** executes the correction process of correcting the virtual acceleration rate VG and transmits the corrected virtual acceleration rate CVG to the target driving force calculation section **125**. Note that the correction section **124** does not execute the correction process when the determination result JR indicating not to perform correction is received. In such a case, the corrected virtual acceleration rate CVG is equal to the virtual acceleration rate VG before correction.

[0110] FIG. **6** is referred to again. The target driving force calculation section **125** acquires the corrected virtual acceleration rate CVG from the correction section **124** and calculates a target driving force for causing the acceleration rate of the electric vehicle **100** to be the virtual acceleration rate CVG. For example, the target driving force calculation section **125** transforms the virtual acceleration rate CVG into the target driving force F.sub.veh by using a simplified inverse model of the electric vehicle **100**, as represented by the following expression. In the following expression, m is the vehicle weight of the electric vehicle **100**, and F.sub.load is an actual travel resistance acting on the electric vehicle **100**. The on-demand mode driving force calculation section **120** outputs the target driving force calculated by the target driving force calculation section **125**.

$$[00001] F_{\text{veh}} = m * \text{CVG} - F_{\text{load}}$$

[0111] The functional configuration of the on-demand mode driving force calculation section **120** according to the present embodiment can be made as described above. FIG. **11** is a flowchart showing a process flow of processes that are performed by the on-demand mode driving force calculation section **120** based on the functional configuration. The process flow shown in FIG. **11** is repeatedly executed at predetermined process intervals.

[0112] In step S**200**, the on-demand mode driving force calculation section **120** acquires various information. For example, the on-demand mode driving force calculation section **120** acquires the information on the target virtual vehicle STV from the mode information acquisition section **110**. The on-demand mode driving force calculation section **120** acquires the information on the operation state AS of the accelerator pedal **22** and the information on the traveling state RS of the electric vehicle **100** from the sensor system **50**.

[0113] Next, in step S**210**, the on-demand mode driving force calculation section **120** refers to the vehicle model database D**10** and reads a vehicle model **200** (target vehicle model) corresponding to the target virtual vehicle STV.

[0114] Next, in step S**220**, the on-demand mode driving force calculation section **120** calculates the virtual acceleration rate VG of the target virtual vehicle responding to an operation of the accelerator pedal **22**, by using the target vehicle model.

[0115] Next, in step S**230**, the on-demand mode driving force calculation section **120** determines whether or not to perform correction of the virtual acceleration rate VG. It is determined by the correction determination section **123** whether or not to perform correction. When correction is performed (step S**230**; Yes), the virtual acceleration rate VG is corrected (step S**240**), and thereafter the process moves to step S**250**. When correction is not performed (step S**230**; No), the process moves to step S**250**, without the virtual acceleration rate VG being corrected.

[0116] Next, in step S**250**, the on-demand mode driving force calculation section **120** calculates a target driving force for causing the acceleration rate of the electric vehicle **100** to be the virtual acceleration rate CVG. Thereafter, the current processes are terminated.

[0117] As described above, according to the present embodiment, when the virtual acceleration rate VG exceeds the realizable acceleration rate of the electric vehicle **100** during the acceleration

period of the electric vehicle **100**, the virtual acceleration rate VG is corrected in such a manner that changes over time in virtual acceleration rate VG during the acceleration period are reshaped according to the excess amount. The corrected virtual acceleration rate CVG realizes an equivalent feel of acceleration to a feel of acceleration realized by the virtual acceleration rate VG before correction. According to the present embodiment, the target driving force for causing the acceleration rate of the electric vehicle **100** to be the virtual acceleration rate CVG is calculated. Thus, even when the acceleration characteristic of a target virtual vehicle exceeds the acceleration capability of the electric vehicle **100**, it is possible to allow the driver to experience an equivalent feel of acceleration to a feel of acceleration of the target virtual vehicle. Moreover, it is possible to increase virtual vehicle variations of which a feel of acceleration can be reproduced in the on-demand mode, and hence to enhance the degree of user satisfaction.

4.1.2 Example of Configuration of Vehicle Model

[0118] Here, an example of the configuration of a vehicle model **200** managed by the vehicle model database **D10** is described. FIG. **12** shows an example of the configuration of a vehicle model **200**. The vehicle model **200** includes a control model **210** and a plant model **220**. The control model **210** simulates a control system related to the powertrain of the virtual vehicle. The plant model **220** simulates an acceleration or deceleration behavior of the virtual vehicle according to a control signal from the control model **210**. The plant model **220** includes a powertrain model that operates based on a control signal from the control model **210**, and a model for simulating a behavior of the virtual vehicle as a result of action of virtual driving force output by the powertrain model. The control model **210** can also simulate a control system that calculates a required output to the powertrain of the virtual vehicle. The plant model **220** can also simulate a physical restriction on the required output to the powertrain.

[0119] Note that the respective specifications of the control model **210** and the plant model **220** differ from type to type of a powertrain system. For example, the configurations of a control system, a transmission, and a drive system differ between CONV and HEV. Accordingly, a vehicle model **200** for CONV and a vehicle model **200** for HEV have mutually different specifications for both the control model **210** and the plant model **220**. In the example shown in FIG. **12**, a case is particularly shown in which the virtual vehicle is an automatic transmission vehicle (AT vehicle) that includes an internal combustion engine.

[0120] The control model **210** includes a target virtual driving force calculation section **211** and a required output calculation section **212**. The target virtual driving force calculation section **211** calculates a virtual driving force (target virtual driving force) required at output of the powertrain of the virtual vehicle, based on an accelerator operation amount and a vehicle speed. For example, the target virtual driving force calculation section **211** performs the calculation by using a map that gives a target virtual driving force to a combination of an accelerator operation amount and a vehicle speed. The required output calculation section **212** calculates a required output of the powertrain such that the calculated target virtual driving force is satisfied. The calculated required output includes a target engine torque of the internal combustion engine and a target gear stage of the transmission. The control model **210** transmits the calculated required output to the plant model **220**.

[0121] The plant model **220** includes an internal combustion engine model **221**, a transmission model **222**, a drive system model **223**, and a vehicle and environment model **224**. The internal combustion engine model **221**, the transmission model **222**, and the drive system model **223** are models for the powertrain from the drive source up to the drive wheels. The vehicle and environment model **224** is a model for simulating a behavior of the virtual vehicle as a result of action of the virtual driving force output by the powertrain model.

[0122] The internal combustion engine model **221** is a model of the internal combustion engine of the virtual vehicle. For example, the internal combustion engine model **221** simulates an operation of the internal combustion engine responding to an input of the target engine torque. The internal

combustion engine model **221** outputs a virtual engine speed and a virtual engine torque. In the internal combustion engine model **221**, parameters **201** that can be changed according to a target virtual vehicle are, for example, engine maximum torque, engine torque responsiveness, and the like.

[0123] The transmission model **222** is a model of the transmission of the virtual vehicle. For example, the transmission model **222** simulates an operation of the transmission responding to an input of the target gear stage. The transmission model **222** outputs a virtual transmission output torque, based on a gear ratio that is determined by the virtual engine torque output by the internal combustion engine model **221** and the virtual gear stage. The transmission model **222** includes a stepped transmission model, which simulates a stepped transmission, and a continuously variable transmission model, which simulates a continuously variable transmission. One of the stepped transmission model and the continuously variable transmission model is selected according to the target virtual vehicle. In the transmission model **222**, parameters **201** that can be changed according to a target virtual vehicle are, for example, each gear ratio, gear change timing, and the like. In the case of the stepped transmission model, each gear ratio means a gear ratio at each gear stage.

[0124] The drive system model **223** is a model of the drive system of the virtual vehicle. For example, in the drive system model **223**, a mechanical structure from the transmission to the drive wheels is modeled. The drive system model **223** calculates a drive wheel torque by using the virtual transmission output torque output by the transmission model **222** and a predetermined reduction ratio, and outputs a virtual driving force for the virtual vehicle. In the drive system model **223**, parameters **201** that can be changed according to a target virtual vehicle are, for example, reduction ratio, propeller shaft maximum allowable torque, and the like.

[0125] The vehicle and environment model **224** is a model representing a mechanical characteristic of the virtual vehicle and a travel environment around the virtual vehicle. The vehicle and environment model **224** calculates a travel resistance acting on the virtual vehicle, based on the travel environment around the virtual vehicle. The vehicle and environment model **224** then simulates acceleration or deceleration behavior of the virtual vehicle, based on the virtual driving force output from the drive system model **223**, the calculated travel resistance, and the mechanical characteristic of the virtual vehicle. The vehicle and environment model **224** outputs a virtual acceleration rate, based on the acceleration or deceleration behavior of the virtual vehicle. In the vehicle and environment model **224**, parameters **201** that can be changed according to a target virtual vehicle are, for example, vehicle weight, tire diameter, CD value, and the like.

[0126] Each vehicle model **200** can be configured as described above. The vehicle model **200** shown in FIG. **4** is an example. In a vehicle model **200**, part of a model can be configured more minutely, depending on an event desired to be emphasized. For example, a case is considered in which a shock or a response is desired to be emphasized that accompanies a change in engagement between a gear of the transmission and a clutch at a time of kickdown. In such a case, the transmission model **222** may be configured to reproduce details, such as the planetary, Ravigneaux, or other gearing system of the transmission, inertia of each constituent element, and a change in transmission path between when the clutch is engaged and when the clutch is not engaged. When a computational load on a vehicle model **200** is desired to be lightened, the transmission model **222** may be simply configured to reproduce only gear ratios.

5 Sound Control Device

[0127] The control device **101** according to the present embodiment may function as a sound control device that, in respect of control of the electric vehicle **100**, controls the in-vehicle speaker **21** in such a manner that a pseudo-engine sound according to a target virtual vehicle is output. More specifically, the control device **101** functions as the sound control device by the processing circuitry **102** executing the computer program **104** for in-vehicle speaker control stored in the storage device **103**. Hereinafter, control of the electric vehicle **100** by the sound control device is described.

[0128] FIG. 13 shows a functional configuration of the sound control device **101b**. The sound control device **101b** causes the in-vehicle speaker **21** to produce a pseudo-engine sound that imitates an engine sound of a virtual vehicle including an internal combustion engine.

[0129] The mode information acquisition section **110** transmits information on a selected control mode and information on a target virtual vehicle to a pseudo-engine sound generation section **160**.

[0130] The pseudo-engine sound generation section **160** functions when the control mode is the on-demand mode and when the target virtual vehicle is a virtual vehicle including an internal combustion engine. At the time, in the sound control device **101b**, a vehicle model **200** (target vehicle model) corresponding to the target virtual vehicle is read from the vehicle model database **D10**, based on the information on the target virtual vehicle from the mode information acquisition section **110**. A parameter **201** is set according to the target virtual vehicle. The pseudo-engine sound generation section **160** generates pseudo-engine sound, based on a virtual engine torque and a virtual engine speed calculated by using the target vehicle model.

[0131] The pseudo-engine sound generation section **160** refers to the storage device **103** and acquires a sound source of the pseudo-engine sound related to the target virtual vehicle. A sound source of a pseudo-engine sound related to each virtual vehicle including an internal combustion engine may be stored in the storage device **103**.

[0132] The pseudo-engine sound generation section **160** includes a process **161** of calculating an engine sound pressure and a process **162** of calculating an engine sound frequency. In the process **161**, the sound pressure of the pseudo-engine sound is calculated from the virtual engine torque by using a sound pressure map **M11**. The sound pressure map **M11** is created in such a manner that the larger the virtual engine torque is, the larger the sound pressure is. In the process **162**, the frequency of the virtual engine sound is calculated from the virtual engine speed by using a frequency map **M12**. The frequency map **M12** is created in such a manner that the larger the virtual engine speed is, the higher the frequency is. The virtual engine torque and the virtual engine speed change according to an operation of a driving operation member by the driver.

[0133] The sound control device **101b** outputs the pseudo-engine sound generated by the pseudo-engine sound generation section **160** from the in-vehicle speaker **21**. Sound control related to pseudo-engine sound is performed by the sound control device **101b** as described above, whereby when the control mode is the on-demand mode, it is possible to provide the driver further with a sense of reality, as if the driver drives the target virtual vehicle.

6 Display Control Device

[0134] When the control mode is the on-demand mode, the control device **101** according to the present embodiment may function as a display control device that controls the HMI **20** in such a manner that a virtual engine speed and a virtual gear stage of the target virtual vehicle are displayed. Thus, it is possible to provide the driver further with a sense of reality, as if the driver drives the target virtual vehicle.

7 Others

[0135] The electric vehicle **100** according to the embodiment is an FF vehicle with the single electric motor **2** that drives the front wheels. However, the technical characteristics of the embodiment can also be applied to an electric vehicle with two electric motors that are laid at the front and the rear and drive the front wheels and the rear wheels, respectively. Moreover, application is also possible to an electric vehicle that includes an in-wheel motor in each wheel.

[0136] The technical characteristics of the embodiment are not only applied to battery electric vehicles, but can also be applied widely to electric vehicles that use an electric motor for a traction power unit. For example, the technical characteristics of the embodiment can be applied to hybrid battery electric vehicles (HEVs) or plug-in hybrid battery electric vehicles (PHEVs) that have a mode in which the vehicle travels only with the driving force of an electric motor. Moreover, application is also possible to fuel cell electric vehicles (FCEVs) in which electric energy generated by a fuel cell is supplied to an electric motor.

Claims

1. An electric vehicle comprising: an electric motor as a drive source; an accelerator pedal; a storage device storing a database, the database being configured to manage a plurality of vehicle models created by modeling a plurality of virtual vehicles that differs in acceleration characteristic responding to a driving operation by a driver; and processing circuitry configured to: read a target vehicle model corresponding to a target virtual vehicle from the database, the target virtual vehicle being selected by the driver from among the plurality of virtual vehicles; calculate a virtual acceleration rate of the target virtual vehicle responding to an operation of the accelerator pedal by using the target vehicle model, based on an operation state of the accelerator pedal and a traveling state of the electric vehicle; determine whether or not the virtual acceleration rate exceeds a realizable acceleration rate of the electric vehicle during an acceleration period of the electric vehicle in which the accelerator pedal is depressed; perform a correction process when it is determined that the virtual acceleration rate exceeds the realizable acceleration rate of the electric vehicle during the acceleration period, the correction process correcting the virtual acceleration rate in such a manner as to reshape, according to an excess amount, changes over time in the virtual acceleration rate during the acceleration period; and control the electric motor in such a manner that an acceleration rate of the electric vehicle becomes the corrected virtual acceleration rate.
2. The electric vehicle according to claim 1, wherein in the correction process, the processing circuitry is configured to correct the virtual acceleration rate in such a manner that a jerk at a time when the virtual acceleration rate rises becomes larger than the jerk before the correction during the acceleration period.
3. The electric vehicle according to claim 1, wherein in the correction process, the processing circuitry is configured to correct the virtual acceleration rate in such a manner that the virtual acceleration rate temporarily drops before the virtual acceleration rate rises during the acceleration period.
4. The electric vehicle according to claim 1, wherein in the correction process, the processing circuitry is configured to correct the virtual acceleration rate in such a manner that a period before the virtual acceleration rate rises becomes shorter than the period before the correction during the acceleration period.
5. The electric vehicle according to claim 1, wherein the processing circuitry is configured to: calculate a target driving force for the electric vehicle such that the acceleration rate of the electric vehicle becomes the virtual acceleration rate; and change motor torque output by the electric motor such that the target driving force is applied to the electric vehicle.
6. A control device of an electric vehicle including an electric motor as a drive source and an accelerator pedal, the control device comprising: a storage device storing a database, the database being configured to manage a plurality of vehicle models created by modeling a plurality of virtual vehicles that differs in acceleration characteristic responding to a driving operation by a driver; and processing circuitry configured to: read a target vehicle model corresponding to a target virtual vehicle from the database, the target virtual vehicle being selected by the driver from among the plurality of virtual vehicles; calculate a virtual acceleration rate of the target virtual vehicle responding to an operation of the accelerator pedal by using the target vehicle model, based on an operation state of the accelerator pedal and a traveling state of the electric vehicle; determine whether or not the virtual acceleration rate exceeds a realizable acceleration rate of the electric vehicle during an acceleration period of the electric vehicle in which the accelerator pedal is depressed; perform a correction process when it is determined that the virtual acceleration rate exceeds the realizable acceleration rate of the electric vehicle during the acceleration period, the correction process correcting the virtual acceleration rate in such a manner as to reshape, according to an excess amount, changes over time in the virtual acceleration rate during the acceleration

period; and control the electric motor in such a manner that an acceleration rate of the electric vehicle becomes the corrected virtual acceleration rate.

7. The control device according to claim 6, wherein in the correction process, the processing circuitry is configured to correct the virtual acceleration rate in such a manner that a jerk at a time when the virtual acceleration rate rises becomes larger than the jerk before the correction during the acceleration period.

8. The control device according to claim 6, wherein in the correction process, the processing circuitry is configured to correct the virtual acceleration rate in such a manner that the virtual acceleration rate temporarily drops before the virtual acceleration rate rises during the acceleration period.

9. The control device according to claim 6, wherein in the correction process, the processing circuitry is configured to correct the virtual acceleration rate in such a manner that a period before the virtual acceleration rate rises becomes shorter than the period before the correction during the acceleration period.
