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Inventor(s)	Okuda; Koichi et al.

Method for training a mapping for outputting an abnormality determination variable for a specific component mounted on a vehicle

Abstract

A training method includes: a simulation step outputting, by a simulator, a characteristic variable based on an input parameter set, the parameter set being input to the simulator and indicating that a specific component is presumed to have an abnormality in advance; and a training step updating, by a training device, mapping based on an input training data and an input teaching data, the input variables being input to the training device as the training data, the input variables including the characteristic variable output in the simulation step, the abnormality determination variable being input to the training device as the teaching data, the abnormality determination variable indicating that the specific component has the abnormality.

Inventors: Okuda; Koichi (Toyota, JP), Tabata; Atsushi (Okazaki, JP), Imamura; Ken (Toyota, JP)

Applicant: TOYOTA JIDOSHA KABUSHIKI KAISHA (Toyota, JP)

Family ID: 1000008751093

Assignee: TOYOTA JIDOSHA KABUSHIKI KAISHA (Toyota, JP)

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Primary Examiner: Chad; Aniss

Assistant Examiner: Cooley; Chase L

Attorney, Agent or Firm: Oliff PLC

Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION
(1) This application claims priority to Japanese Patent Application No. 2020-150018 filed on Sep. 7, 2020, incorporated herein by reference in its entirety.
BACKGROUND
1. Technical Field
(2) The present disclosure relates to a training method.

2. Description of Related Art

(3) Japanese Unexamined Patent Application Publication No. 2014-092504 (JP 2014-092504 A) describes an abnormality determination apparatus for an automatic transmission. The abnormality determination apparatus acquires vibration data indicating a transition of vibration of the automatic transmission. The abnormality determination apparatus calculates an upper limit value of a vibration acceleration based on previous vibration data. The abnormality determination apparatus calculates a vibration acceleration based on the newly acquired vibration data. When the vibration acceleration is higher than the upper limit value, the abnormality determination apparatus determines that the automatic transmission has an abnormality.

SUMMARY

(4) In order that the abnormality determination apparatus as in JP 2014-092504 A may accurately determine whether the automatic transmission has an abnormality, it is necessary to appropriately set the upper limit value of the vibration acceleration. However, the abnormality of the automatic transmission does not occur very frequently. Therefore, the upper limit value of the vibration acceleration needs to be set based on few data. Thus, the upper limit value of the vibration acceleration may be inappropriate.

(5) Although the description is given above taking the abnormality determination apparatus for the automatic transmission as an example, the same applies to abnormality determination for other apparatuses. The same applies also to a case of setting a criterion of abnormality determination based on previous data, as well as the case of setting the threshold such as the upper limit value of the vibration acceleration as in the example described above.

(6) A first aspect of the present disclosure relates to a training method to train mapping for training abnormality determination by using a simulator, a storage, and a training device. The simulator is configured to output a characteristic variable related to at least one of noise and vibration of a vehicle by an input parameter set having a plurality of condition parameters related to conditions of the vehicle. The storage stores mapping data defining the mapping for outputting, as an output variable, an abnormality determination variable indicating an occurrence possibility about an abnormality of a specific component mounted on the vehicle. The mapping data has the characteristic variable as at least one of a plurality of input variables. The training device is configured to update the mapping data defining the mapping stored in the storage by the input variables that are input as training data and the abnormality determination variable paired with the training data that are input as teaching data. The method includes a simulation step and a training step. The simulation step outputs, by the simulator, the characteristic variable based on the input parameter set. The training step updates, by the training device, the mapping based on the input training data and the input teaching data. The input variables is input to the training device as the teaching data. The abnormality determination variable indicate that the specific component has the abnormality.

(7) According to the first aspect, even if the abnormality of the specific component actually occurs at a low frequency, a large number of characteristic variables under the assumption that the abnormality occurs can be obtained by the simulator while changing numerical values of the condition parameters as appropriate. The mapping of the mapping data is updated based on a set of a large number of pieces of the teaching data and the training data including, as the input variables, the characteristic variables under the assumption that the abnormality occurs, thereby increasing a probability that the mapping can output an appropriate output variable.

(8) In the first aspect, the specific component may be a component on a power transmission path from a drive source of the vehicle to a driving wheel of the vehicle.

(9) According to the configuration described above, the mapping of the mapping data can appropriately be updated for the component on the power transmission path that is likely to cause the vibration or the noise of the vehicle.

(10) In the first aspect, one of the condition parameters may be a specific parameter indicating a

property of the specific component. In the simulation step, a parameter set having the specific parameter that falls out of a predetermined normal range may be input as the parameter set indicating that the specific component is presumed to have the abnormality in advance.

(11) According to the configuration described above, the specific parameter falls out of the normal range, and therefore the parameter set input to the simulator may be regarded as the parameter set when the specific component actually has the abnormality. Thus, the parameter set that securely reflects the abnormal state of the specific component can be input to the simulator.

(12) In the first aspect, the characteristic variable may indicate an acceleration of the vehicle in a predetermined specific direction.

(13) According to the configuration described above, the training effect of the mapping of the mapping data is increased in a case where the acceleration of the vehicle may change depending on whether the specific component has the abnormality.

(14) In the first aspect, when energy of the vibration of the vehicle or the noise of the vehicle on a unit frequency basis is a power spectrum, the characteristic variable may be a variable indicating a power spectrum density at a predetermined specific frequency or in a predetermined specific frequency band.

(15) According to the configuration described above, the training effect of the mapping of the mapping data is increased in a case where the power spectrum of the vibration or the noise may change depending on whether the specific component has the abnormality.

(16) In the first aspect, the characteristic variable may indicate a frequency at a maximum amplitude of the vibration of the vehicle or the noise of the vehicle.

(17) According to the configuration described above, the training effect of the mapping of the mapping data is increased in a case where the vibration or the noise may occur at the specific frequency depending on whether the specific component has the abnormality.

(18) In the first aspect, the characteristic variable may indicate a duration of the vibration of the vehicle or the noise of the vehicle.

(19) According to the configuration described above, the training effect of the mapping of the mapping data is increased in a case where the function of reducing the vibration or the noise may vary depending on whether the specific component has the abnormality.

(20) In the first aspect, the characteristic variable may indicate a decrease rate of the vibration of the vehicle or the noise of the vehicle per unit time.

(21) According to the configuration described above, the training effect of the mapping of the mapping data is increased in the case where the function of reducing the vibration or the noise may vary depending on whether the specific component has the abnormality.

(22) In the first aspect, one of the condition parameters may be a vehicle speed.

(23) According to the configuration described above, the characteristic variable is calculated as a result of simulation executed by the simulator based on the vehicle speed greatly related to the vibration or the noise of the vehicle. Thus, there is a greater expectation that an accurate characteristic variable is obtained.

(24) In the first aspect, one of the condition parameters may be an operation amount of an accelerator pedal.

(25) In the configuration described above, the operation amount of the accelerator pedal is related to acceleration or deceleration of the vehicle. The acceleration or deceleration of the vehicle is greatly related to the vibration or the noise of the vehicle. According to the configuration described above, there is a greater expectation that an accurate characteristic variable is obtained.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

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

(2) FIG. **1** is a schematic structural diagram of a vehicle;

(3) FIG. **2** is an explanatory drawing illustrating relationships between gear stages of an automatic transmission and engagement elements;

(4) FIG. **3** is a flowchart illustrating determination control;

(5) FIG. **4** is an explanatory drawing illustrating a power spectrum;

(6) FIG. **5** is an explanatory drawing illustrating a rigidity value of a damper;

(7) FIG. **6** is a structural diagram of a simulator;

(8) FIG. **7** is a flowchart illustrating training control; and

(9) FIG. **8** is a schematic structural diagram of a vehicle according to a modified example.

DETAILED DESCRIPTION OF EMBODIMENTS

(10) One embodiment of the present disclosure is described below with reference to FIG. **1** to FIG. **7**. First, the overall structure of a vehicle **100** is described. As illustrated in FIG. **1**, the vehicle **100** includes an internal combustion engine **10**, a damper **15**, a power split device **20**, an automatic transmission **30**, driving wheels **69**, a hydraulic apparatus **65**, a first motor generator **61**, and a second motor generator **62**.

(11) The internal combustion engine **10** has a crankshaft **11** that is an output shaft. The crankshaft **11** is coupled to the power split device **20** via the damper **15**. The damper **15** has a damper body **16** and an attenuator **17**. The damper body **16** is interposed between the crankshaft **11** and the power split device **20**, and has a plurality of coil springs arranged in a circumferential direction. Through elastic deformation of the coil springs of the damper body **16**, the damper body **16** transmits a torque between the crankshaft **11** and the power split device **20** while suppressing torsional vibration between the crankshaft **11** and the power split device **20** due to, for example, torque fluctuation. The attenuator **17** is interposed between the crankshaft **11** and the power split device **20**. The attenuator **17** damps vibration due to restoration of the damper body **16** by restricting an abrupt change along with the restoration after the elastic deformation of the damper body **16**.

(12) The power split device **20** is a planetary gearing mechanism including a sun gear S, a ring gear R, and a carrier C. The carrier C of the power split device **20** is coupled to the crankshaft **11** via the damper **15**. The sun gear S is coupled to a rotational shaft **61**A of the first motor generator **61**. A ring gear shaft RA that is an output shaft of the ring gear R is coupled to a rotational shaft **62**A of the second motor generator **62**. The ring gear shaft RA is also coupled to the automatic transmission **30**.

(13) The automatic transmission **30** has an input shaft **41** and an output shaft **42**. The input shaft **41** of the automatic transmission **30** is coupled to the ring gear shaft RA. The output shaft **42** of the automatic transmission **30** is coupled to the right and left driving wheels **69** via a differential gear (not illustrated).

(14) When the internal combustion engine **10** is driven and a torque is input to the carrier C of the power split device **20** from the crankshaft **11**, the torque is split into a torque on the sun gear S side and a torque on the ring gear R side. When the first motor generator **61** operates as a motor and a torque is input to the sun gear S of the power split device **20**, the torque is split into a torque on the carrier C side and a torque on the ring gear R side.

(15) When the second motor generator **62** operates as a motor and a torque is input to the ring gear shaft RA, the torque is transmitted to the automatic transmission **30**. When a torque from the driving wheels **69** is input to the second motor generator **62** via the ring gear shaft RA, the second motor generator **62** functions as a generator. Thus, a regenerative braking force can be generated in the vehicle **100**.

(16) The automatic transmission **30** includes a first planetary gearing mechanism **30**A, a second planetary gearing mechanism **30**B, a first clutch C**1**, a second clutch C**2**, a first brake mechanism B**1**, a second brake mechanism B**2**, and a one-way clutch F**1**.

(17) The first planetary gearing mechanism **30**A includes a sun gear **31**, a ring gear **32**, pinion gears **33**, and a carrier **34**. The sun gear **31** is coupled to the ring gear **32** via the pinion gears **33**. The carrier **34** supports the pinion gears **33**.

(18) The sun gear **31** is coupled to the first brake mechanism B**1**. An engaged state and a disengaged state of the first brake mechanism B**1** are switchable by a pressure of oil supplied to the first brake mechanism B**1**. Specifically, the first brake mechanism B**1** is switched from the disengaged state to the engaged state when the pressure of the oil supplied to the first brake mechanism B**1** increases. In the engaged state of the first brake mechanism B**1**, rotation of the sun gear **31** is braked.

(19) The carrier **34** is coupled to the one-way clutch F**1**. The one-way clutch F**1** restricts rotation of the carrier **34** to one side, and permits rotation of the carrier **34** to the other side. That is, the one-way clutch F**1** is switched to a restricting state for restricting the rotation of the carrier **34** or a permitting state for permitting the rotation of the carrier **34**. The carrier **34** is coupled to the second brake mechanism B**2**. Similarly to the first brake mechanism B**1**, an engaged state and a disengaged state of the second brake mechanism B**2** are switchable by a pressure of oil supplied to the second brake mechanism B**2**. In the engaged state of the second brake mechanism B**2**, the rotation of the carrier **34** is braked.

(20) The second planetary gearing mechanism **30**B includes a sun gear **36**, a ring gear **37**, pinion gears **38**, and a carrier **39**. The sun gear **36** is coupled to the ring gear **37** via the pinion gears **38**. The carrier **39** supports the pinion gears **38**. The carrier **39** is coupled to the output shaft **42**.

(21) In the planetary gearing mechanisms structured as described above, the carrier **34** of the first planetary gearing mechanism **30**A is coupled to the ring gear **37** of the second planetary gearing mechanism **30**B. The ring gear **32** of the first planetary gearing mechanism **30**A is coupled to the carrier **39** of the second planetary gearing mechanism **30**B.

(22) The sun gear **36** of the second planetary gearing mechanism **30**B is coupled to the input shaft **41** via the first clutch C**1**. An engaged state and a disengaged state of the first clutch C**1** are switchable by a pressure of oil supplied to the first clutch C**1**. Specifically, the first clutch C**1** is switched from the disengaged state to the engaged state when the pressure of the oil supplied to the first clutch C**1** increases. In the engaged state of the first clutch C**1**, the sun gear **36** of the second planetary gearing mechanism **30**B rotates together with the input shaft **41**.

(23) The carrier **34** of the first planetary gearing mechanism **30**A is coupled to the input shaft **41** via the second clutch C**2**. Similarly to the first clutch C**1**, an engaged state and a disengaged state of the second clutch C**2** are switchable by a pressure of oil supplied to the second clutch C**2**. In the engaged state of the second clutch C**2**, the carrier **34** of the first planetary gearing mechanism **30**A rotates together with the input shaft **41**. In this embodiment, the first clutch C**1**, the second clutch C**2**, the first brake mechanism B**1**, and the second brake mechanism B**2** are engagement elements.

(24) As illustrated in FIG. **2**, gear stages of the automatic transmission **30** are switched based on combinations of the engaged states or the disengaged states of the first clutch C**1**, the second clutch C**2**, the first brake mechanism B**1**, and the second brake mechanism B**2** and a combination of the restricting state or the permitting state of the one-way clutch F**1**. The automatic transmission **30** can make a total of five gear stages including four gear stages that are "first gear" to "fourth gear" for forward traveling and one gear stage that is "R" for reverse traveling.

(25) In FIG. **2**, a symbol "◯" represents the engaged state of the engagement element such as the first clutch C**1**, and the restricting state of the one-way clutch F**1**. A symbol "(◯)" represents the engaged state or the disengaged state of the second brake mechanism B**2**. A blank field represents the disengaged state of the engagement element such as the first clutch C**1**, and the permitting state of the one-way clutch F**1**. For example, when the gear stage of the automatic transmission **30** is

second gear, the first clutch C**1** and the first brake mechanism B**1** are engaged, the second clutch C**2** and the second brake mechanism B**2** are disengaged, and the one-way clutch F**1** permits rotation.

(26) As illustrated in FIG. **1**, the hydraulic apparatus **65** includes an oil pump **66** and a hydraulic circuit **67** through which oil from the oil pump **66** circulates. The oil pump **66** is a so-called mechanical oil pump configured to operate by receiving a torque of the crankshaft **11**. The hydraulic circuit **67** includes a plurality of solenoid valves (not illustrated). By controlling the solenoid valves, the hydraulic circuit **67** adjusts pressures of oil to be supplied to the first clutch C**1**, the second clutch C**2**, the first brake mechanism B**1**, and the second brake mechanism B**2**. That is, in this embodiment, the engaged states and the disengaged states of the engagement elements such as the first clutch C**1** are controlled through the pressures of the oil by controlling the solenoid valves of the hydraulic circuit **67**.

(27) As illustrated in FIG. **1**, the vehicle **100** includes an accelerator position sensor **72**, a vehicle speed sensor **73**, an acceleration sensor **74**, an indicator **76**, and an accelerator pedal **77**. The accelerator position sensor **72** detects an accelerator operation amount ACC that is an operation amount of the accelerator pedal **77** operated by a driver. The vehicle speed sensor **73** detects a vehicle speed SP of the vehicle **100**. The acceleration sensor **74** detects a vertical acceleration G that is an acceleration in a vertical direction of the vehicle **100**. The vertical acceleration G takes a positive value when the acceleration sensor **74** detects an upward acceleration of the vehicle **100**, and a negative value when the acceleration sensor **74** detects a downward acceleration of the vehicle **100**. The indicator **76** indicates visual information for the driver of the vehicle **100** or the like. Examples of the indicator **76** include a display.

(28) The vehicle **100** includes a controller **90**. For example, the controller **90** is mounted in an engine compartment of the vehicle **100** or in an area between a vehicle cabin and the engine compartment. The acceleration sensor **74** is mounted in the controller **90**. A signal indicating the accelerator operation amount ACC is input to the controller **90** from the accelerator position sensor **72**. A signal indicating the vehicle speed SP is input to the controller **90** from the vehicle speed sensor **73**. A signal indicating the vertical acceleration G is input to the controller **90** from the acceleration sensor **74**.

(29) The controller **90** includes a central processing unit (CPU) **91**, a peripheral circuit **92**, a read-only memory (ROM) **93**, a storage **94**, and a bus **95**. The bus **95** communicably connects the CPU **91**, the peripheral circuit **92**, the ROM **93**, and the storage **94**. The ROM **93** prestores various programs for causing the CPU **91** to execute various types of control. The storage **94** prestores mapping data **94**A. Mapping M**1** defined by the mapping data **94**A outputs an output variable by inputting input variables. The output variable indicates whether the damper **15** has an abnormality. Details of the mapping M**1** are described later. The storage **94** stores, for a predetermined period, data including the accelerator operation amount ACC, the vehicle speed SP, and the vertical acceleration G input to the controller **90**. The peripheral circuit **92** includes a circuit configured to generate a clock signal for defining internal operations, a power supply circuit, and a reset circuit.

(30) In this embodiment, the CPU **91** serves as a training device. The storage **94** serves as a storage that stores mapping data. The damper **15** serves as a specific component mounted on the vehicle **100**. The specific component is a component on a power transmission path from the internal combustion engine **10** that functions as a drive source of the vehicle **100** to the driving wheels **69**.

(31) For example, the CPU **91** controls the internal combustion engine **10**, the first motor generator **61**, the second motor generator **62**, and the automatic transmission **30** by executing various programs stored in the ROM **93**. Specifically, the CPU **91** calculates, based on the accelerator operation amount ACC and the vehicle speed SP, requested vehicle power that is a requested value of power necessary for the vehicle **100** to travel. The CPU **91** determines distribution of torques of the internal combustion engine **10**, the first motor generator **61**, and the second motor generator **62** based on the requested vehicle power. The CPU **91** controls power of the internal combustion

engine **10** and power running and regeneration of the first motor generator **61** and the second motor generator **62** based on the distribution of the torques of the internal combustion engine **10**, the first motor generator **61**, and the second motor generator **62**.

(32) The CPU **91** calculates a target gear stage of the automatic transmission **30** based on the vehicle speed SP and the requested vehicle power. The CPU **91** calculates, based on the target gear stage, target pressures that are target values of the pressures of the oil to be supplied to the first clutch C**1**, the second clutch C**2**, the first brake mechanism B**1**, and the second brake mechanism B**2**. The CPU **91** outputs a control signal Si to the hydraulic apparatus **65** based on the target pressures. Based on the control signal Sl, the hydraulic apparatus **65** changes the pressures of the oil to be supplied to the first clutch C**1**, the second clutch C**2**, the first brake mechanism B**1**, and the second brake mechanism B**2**. For example, when the gear stage of the automatic transmission **30** before shifting is second gear, the first clutch C**1** and the first brake mechanism B**1** are engaged, the second clutch C**2** and the second brake mechanism B**2** are disengaged, and the one-way clutch F**1** permits rotation as illustrated in FIG. **2**. When the target gear stage of the automatic transmission **30** is set to third gear, the disengaged second clutch C**2** is engaged by gradually increasing the pressure of the oil supplied from the hydraulic apparatus **65** to the second clutch C**2** in response to the control signal Si based on the target pressure of the second clutch C**2**. Further, the engaged first brake mechanism B**1** is disengaged by gradually reducing the pressure of the oil supplied from the hydraulic apparatus **65** to the first brake mechanism B**1** in response to the control signal Si based on the target pressure of the first brake mechanism B**1**. As a result, the gear stage of the automatic transmission **30** is shifted from second gear to third gear.

(33) Next, description is given of determination control to be executed by the CPU **91** to determine whether the damper **15** has an abnormality. The ROM **93** prestores a determination program for executing the determination control. While the controller **90** is active, the CPU **91** repeatedly executes the determination control by executing the determination program stored in the ROM **93**.

(34) When the determination control is started, the CPU **91** executes a process of Step S**11** as illustrated in FIG. **3**. In Step S**11**, the CPU **91** determines whether an absolute value of the vertical acceleration G is equal to or higher than a predetermined specified acceleration. For example, the specified acceleration is preset through experiments as a value perceivable by humans at a driver's seat of the vehicle **100**. When the CPU **91** determines in Step S**11** that the absolute value of the vertical acceleration G is lower than the specified acceleration (S**11**: NO), the CPU **91** repeats the process of Step S**11**. When the CPU **91** determines in Step S**11** that the absolute value of the vertical acceleration G is equal to or higher than the specified acceleration (S**11**: YES), the CPU **91** advances the process to Step S**12**.

(35) In Step S**12**, the CPU **91** acquires a transition of the vertical acceleration G in a predetermined period from the timing of the process of Step S**11**. For example, the predetermined period is several seconds. As illustrated in FIG. **4**, the CPU **91** executes fast Fourier transform on the transition of the vertical acceleration G in the predetermined period to create a so-called power spectrum, which is a graph showing vibration energy of the vehicle **100** on a unit frequency basis. The CPU **91** calculates, from the vibration power spectrum, a total of 20 powers associated with a predetermined first frequency to a predetermined 20th frequency as a first power P**1** to a 20th power P**20** in order from the first frequency. The CPU **91** stores the calculated first power P**1** to the calculated 20th power P**20** in the storage **94**. In this embodiment, the first frequency to the 20th frequency are set by dividing a predetermined frequency band perceivable by humans as vibration into 20 equal parts. For example, when a frequency band of less than 20 Hz is set as the frequency band perceivable by humans as vibration, the first frequency to the 20th frequency are set to 1 Hz, 2 Hz . . . in this order. Then, the CPU **91** advances the process to Step S**13** as illustrated in FIG. **3**.

(36) In Step S**13**, the CPU **91** selects a maximum power from among the first power P**1** to the 20th power P**20**. The CPU **91** acquires a frequency associated with the maximum power as a frequency FR. For example, if the maximum power is the first power P**1** as illustrated in FIG. **4**, the frequency

FR is 1 Hz. For example, if the maximum power is the 10th power, the frequency FR is 10 Hz. The CPU **91** stores the acquired frequency FR in the storage **94**. The power spectrum has a dimension corresponding to a square of an amplitude. The frequency FR at which the power spectrum shows the maximum power is a frequency at a maximum amplitude of vibration of the vehicle **100**. Then, the CPU **91** advances the process to Step S**14** as illustrated in FIG. **3**.

(37) In Step S**14** of FIG. **3**, the CPU **91** calculates a duration TA of vibration at the frequency FR. Specifically, the CPU **91** executes band-pass filtering to extract a maximum-amplitude frequency component, that is, a component of the frequency FR acquired in Step S**13** from the transition of the vertical acceleration G in the predetermined period that is acquired in Step S**12**. For example, if the frequency FR is 1 Hz, a component of 0 to 1 Hz is extracted from the transition of the vertical acceleration G. For example, if the frequency FR is 10 Hz, a component of 9 to 10 Hz is extracted from the transition of the vertical acceleration G. The CPU **91** determines a local maximum value and a local minimum value of the vertical acceleration G based on the maximum-amplitude frequency component of the vertical acceleration G. The local maximum value of the vertical acceleration G is a point on the transition of the vertical acceleration G where the vertical acceleration G turns from increase to decrease. The local minimum value of the vertical acceleration G is a point on the transition of the vertical acceleration G where the vertical acceleration G turns from decrease to increase. The CPU **91** calculates, as an amplitude AM, a value obtained by subtracting, from the determined local maximum value, a local minimum value appearing next to the local maximum value. The CPU **91** calculates the amplitude AM for each of a plurality of local maximum values.

(38) The CPU **91** determines a timing when the amplitude AM turns from a value smaller than a predetermined specified amplitude to a value equal to or larger than the specified amplitude in the maximum-amplitude frequency component of the vertical acceleration G. The CPU **91** also determines a timing when the amplitude AM turns from the value equal to or larger than the specified amplitude to a value smaller than the specified amplitude after turning to the value equal to or larger than the specified amplitude. The CPU **91** sets the duration TA of the vibration to a period from the timing when the amplitude AM turns to the value equal to or larger than the specified amplitude to the timing when the amplitude AM turns to the value smaller than the specified amplitude.

(39) When the amplitude AM turns to a value equal to or larger than the specified amplitude, turns to a value smaller than the specified amplitude, and turns again to a value equal to or larger than the specified amplitude in the predetermined period, a plurality of periods of vibration may be calculated. In this case, the CPU **91** sets the longest period as the duration TA. There is also such a case that the amplitude AM turns to a value equal to or larger than the specified amplitude but does not turn to a value smaller than the specified amplitude in the predetermined period. In this case, the CPU **91** calculates the duration TA under the assumption that the amplitude AM turns to a value smaller than the specified amplitude at the end of the predetermined period. The CPU **91** stores the calculated duration TA in the storage **94**. Then, the CPU **91** advances the process to Step S**15**.

(40) In Step S**15**, the CPU **91** calculates a decrease rate DEC of the vibration per unit time at the frequency FR. Specifically, the CPU **91** subtracts an amplitude AM at the end of the duration TA from an amplitude AM at the start of the duration TA. The CPU **91** calculates the decrease rate DEC by dividing the value obtained through the subtraction by the duration TA. The CPU **91** stores the calculated decrease rate DEC in the storage **94**. Then, the CPU **91** advances the process to Step S**16**.

(41) In Step S**16**, the CPU **91** acquires, as a maximum acceleration GM, a maximum value of the absolute value of the vertical acceleration G acquired in the predetermined period. The CPU **91** acquires a vehicle speed SP at the timing of acquisition of the maximum acceleration GM in the predetermined period. The CPU **91** acquires an accelerator operation amount ACC at the timing of acquisition of the maximum acceleration GM in the predetermined period. The CPU **91** stores the

acquired values in the storage **94**. Then, the CPU **91** advances the process to Step S**21**.

(42) In Step S**21**, the CPU **91** acquires various values by accessing the storage **94**. Specifically, the CPU **91** acquires the first power P**1** to the 20th power P**20**, the maximum acceleration GM, the frequency FR, the duration TA, the decrease rate DEC, the vehicle speed SP, and the accelerator operation amount ACC. Then, the CPU **91** advances the process to Step S**22**.

(43) In Step S**22**, the CPU **91** generates the various values acquired in the process of Step S**21** as an input variable x(**1**) to an input variable x(**26**) of the mapping M**1** for determining whether the damper **15** has an abnormality.

(44) The CPU **91** substitutes the first power P**1** to the 20th power P**20** for the input variable x(**1**) to the input variable x(**20**). Specifically, the CPU **91** substitutes the first power P**1** for the input variable x(**1**), the second power P**2** for the input variable x(**2**), . . . , respectively.

(45) The CPU **91** substitutes the maximum acceleration GM for the input variable x(**21**). The CPU **91** substitutes the frequency FR for the input variable x(**22**). The CPU **91** substitutes the duration TA for the input variable x(**23**). The CPU **91** substitutes the decrease rate DEC for the input variable x(**24**). The CPU **91** substitutes the vehicle speed SP for the input variable x(**25**). The CPU **91** substitutes the accelerator operation amount ACC for the input variable x(**26**). Then, the CPU **91** advances the process to Step S**23**.

(46) In Step S**23**, the CPU **91** calculates a value of an output variable y(i) by inputting the input variable x(**1**) to the input variable x(**26**) generated in the process of Step S**22** and an input variable x(**0**) serving as a bias parameter to the mapping M**1** defined by the mapping data **94**A prestored in the storage **94**. Then, the CPU **91** advances the process to Step S**24**.

(47) Examples of the mapping M**1** defined by the mapping data **94**A include a function approximate device that is a fully connected feedforward neural network having one intermediate layer. Specifically, in the mapping M**1** defined by the mapping data **94**A, values of nodes in the intermediate layer are determined such that the input variables x(**1**) to x(**26**) and the input variable x(**0**) serving as the bias parameter are converted by linear mapping defined by a coefficient wFjk (j=1 to m, k=0 to 26), and "m" values obtained through the conversion are substituted into an activation function f. Further, an output variable y(**1**) is determined such that the values of the nodes in the intermediate layer are converted by linear mapping defined by a coefficient wSij (i=1), and individual values obtained through the conversion are substituted into an activation function g. The output variable y(**1**) indicates a possibility that the damper **15** has an abnormality, and changes as, for example, a numerical value between "0" to "1". As the output variable y(**1**) increases, the possibility of the abnormality of the damper **15** increases. The output variable y(**1**) is an abnormality determination variable. Examples of the activation function f of this embodiment include a rectified linear unit (ReLU) function. Examples of the activation function g include a sigmoid function. A method for training the mapping M**1** is described later.

(48) In Step S**24**, the CPU **91** determines whether the output variable y(**1**) is larger than a predetermined threshold. For example, the threshold is "0.5". When the CPU **91** determines in Step S**24** that the output variable y(**1**) is larger than the threshold (S**24**: YES), the CPU **91** advances the process to Step S**31**.

(49) In Step S**31**, the CPU **91** determines that the damper **15** has an abnormality. Then, the CPU **91** advances the process to Step S**32**. In Step S**32**, the CPU **91** outputs, to the indicator **76**, a signal for causing the indicator **76** to indicate that the damper **15** has an abnormality. Then, the CPU **91** terminates the current determination control.

(50) When the CPU **91** determines that the output variable y(**1**) is equal to or smaller than the threshold (S**24**: NO), the CPU **91** advances the process to Step S**41**. In Step S**41**, the CPU **91** determines that the damper **15** has no abnormality. Then, the CPU **91** terminates the current determination control.

(51) Next, description is given of the method for training the mapping M**1** defined by the mapping data **94**A. First, description is given of a simulator **200** to be used for training the mapping M**1**. As

illustrated in FIG. **6**, the simulator **200** includes a CPU **210**, a peripheral circuit **220**, a ROM **230**, a storage **240**, and a bus **250**. Although illustration is omitted, the simulator **200** is communicable with the controller **90** through a removal external cable. The bus **250** communicably connects the CPU **210**, the peripheral circuit **220**, the ROM **230**, and the storage **240**. The ROM **230** prestores various programs for causing the CPU **210** to execute various processes. The peripheral circuit **220** includes a circuit configured to generate a clock signal for defining internal operations, a power supply circuit, and a reset circuit. The storage **240** stores model data **241** for simulating vibration of the vehicle **100**. The model data **241** defines a vehicle model **300**, which is a model of the structure of the vehicle **100**.

(52) The vehicle model **300** defines a driving wheel **310**, a suspension **320**, a frame **330**, a mount **340**, and a drive system **350**. The frame **330** is assumed to be a skeletal component that supports components mounted on the vehicle **100**.

(53) In the vehicle model **300**, the frame **330** is in contact with a road via the suspension **320** and the driving wheel **310**. Therefore, vibration of the frame **330** supported on the road via the driving wheel **310** and the suspension **320** can be calculated based on a coupled dynamical model including a spring rate **310**K and a mass **310**M of the driving wheel **310** and a spring rate **320**K and a damping coefficient **320**D of the suspension **320**. In the vehicle model **300**, the spring rate **310**K and the mass **310**M of the driving wheel **310** are set equal to respective design values in the vehicle **100**. In the vehicle model **300**, the spring rate **320**K and the damping coefficient **320**D of the suspension **320** are set equal to respective design values in the vehicle **100**. In this embodiment, the spring rate **310**K, the mass **310**M, the spring rate **320**K, and the damping coefficient **320**D are fixed values and do not change.

(54) In the vehicle model **300**, the frame **330** supports the drive system **350** via the mount **340**. Therefore, vibration transmitted from the drive system **350** to the frame **330** can be calculated based on a coupled dynamical model including a spring rate **340**K and a damping property **340**D of the mount **340** and a mass **350**M of the drive system **350**. In the vehicle model **300**, the spring rate **340**K and the damping property **340**D of the mount **340** are set equal to respective design values in the vehicle **100**. In the vehicle model **300**, the mass **350**M of the drive system **350** is set equal to its design value in the vehicle **100**. The drive system **350** is a single object serving as a vibration source assuming the individual apparatuses ranging from the internal combustion engine **10** to the automatic transmission **30** in the actual vehicle **100**. In this embodiment, the spring rate **340**K, the damping property **340**D, and the mass **350**M are fixed values and do not change.

(55) A plurality of condition parameters related to conditions of the vehicle **100** can be input to the model data **241**. In this embodiment, the condition parameters are a rigidity value K of a damper, a hysteresis value H of the damper, a gap value GA of the damper, the vehicle speed SP, and the accelerator operation amount ACC. In the model data **241**, the damper is assumed to be the damper **15** of the vehicle **100**.

(56) The rigidity value K of the damper is represented by an input torque Tin necessary to cause a unit torsion angle in the damper **15**. When a relationship between a torsion angle Φ and the input torque Tin is represented by a Cartesian coordinate system as illustrated in FIG. **5**, the rigidity value K corresponds to a derivative, that is, an inclination of a line indicating the relationship between the torsion angle Φ and the input torque Tin. The torsion angle Φ is a difference between an angular position of an input shaft of the damper **15** and an angular position of an output shaft of the damper **15**.

(57) In the damper **15** of the vehicle **100** assumed in the model data **241**, the rigidity value K changes within a normal range from a first value K**1** to a third value K**3** depending on the torsion angle θ. Specifically, when the torsion angle Φ is equal to or larger than "0" and smaller than a first specified value Φ**1**, the rigidity value K is the first value K**1** as illustrated in FIG. **5**. When the torsion angle Φ is equal to or larger than the first specified value Φ **1** and smaller than a second specified value Φ**2**, the rigidity value K is the second value K**2** larger than the first value K**1**. When

the torsion angle Φ is equal to or larger than the second specified value $\Phi2$, the rigidity value K is the third value K**3** larger than the second value K**2**.

(58) In the damper **15** of the vehicle **100**, the rigidity value K may fall out of the normal range due to a change over time. Examples of the change over time include a change in the property of a material for a component of the damper **15** due to a fine crack in the component of the damper **15** or repetitive exposure to temperature change. In the model data **241**, arbitrary values including values outside the normal range can be input as the rigidity value K.

(59) The hysteresis value H of the damper is an absolute value of a difference between an input torque Tin necessary to cause a predetermined torsion angle Φ by increasing the input torque Tin to the damper **15** and an input torque Tin necessary to cause the predetermined torsion angle Φ by reducing the input torque Tin to the damper **15**.

(60) In the damper **15** of the vehicle **100** assumed in the model data **241**, the necessary input torque Tin is larger when causing the predetermined torsion angle Φ by increasing the input torque Tin to the damper **15**. In the damper **15**, the hysteresis value H is approximately a constant value H**1** irrespective of the value of the torsion angle Φ. However, the hysteresis value H may change to some degree due to an external environment such as temperature or manufacturing variations of the damper **15**. In consideration of this change, the normal range of the hysteresis value H of the damper **15** is, for example, a range of ±5% of the constant value H**1**.

(61) The hysteresis value H of the damper may fall out of the normal value range due to a change over time similarly to the rigidity value K. In the model data **241**, arbitrary values including values outside the normal range can be input as the hysteresis value H.

(62) The gap value GA of the damper is a rotation angle of the input shaft of the damper **15** that is required to start rotation of the output shaft of the damper **15** when the input shaft is rotated in a state in which the torsion angle Φ of the damper **15** is "0". That is, the gap value GA of the damper reflects a clearance in a rotational direction between an element on the input shaft side of the damper **15** and an element on the output shaft side of the damper **15**. This clearance may be referred to as "play" or "backlash".

(63) In the damper **15** of the vehicle **100** assumed in the model data **241**, dimensional values of the components of the damper **15** are preset. Therefore, the gap value GA is a constant value GA**1**. However, the gap value GA may change to some degree due to an external environment such as temperature or manufacturing variations of the damper **15**. In consideration of this change, the normal range of the gap value GA of the damper **15** is, for example, a range of ±1% of the constant value GA**1**.

(64) The gap value GA of the damper may fall out of the normal value range due to a change over time. In particular, the components of the damper **15** may be worn out or partially chipped along with use. Therefore, the gap value GA of the damper may fall out of the normal value range. In the model data **241**, arbitrary values including values outside the normal range can be input as the gap value GA.

(65) In the vehicle **100** assumed in the model data **241**, a value to be generated as the vehicle speed SP has a limit. Further, the stroke of the accelerator pedal **77** has a limit. Therefore, a value to be generated as the accelerator operation amount ACC has a limit. In the model data **241**, arbitrary values within a predetermined vehicle speed range can be input as the vehicle speed SP. In the model data **241**, arbitrary values within a predetermined operation amount range can be input as the accelerator operation amount ACC.

(66) When the rigidity value K of the damper, the hysteresis value H of the damper, the gap value GA of the damper, the vehicle speed SP, and the accelerator operation amount ACC are input to the model data **241**, the CPU **210** of the simulator **200** outputs characteristic variables related to vibration of the vehicle **100** by using the vehicle model **300**. A set of the condition parameters, that is, the rigidity value K of the damper, the hysteresis value H of the damper, the gap value GA of the damper, the vehicle speed SP, and the accelerator operation amount ACC that are input to the

model data **241** is hereinafter referred to as "parameter set". The rigidity value K of the damper, the hysteresis value H of the damper, and the gap value GA of the damper that are input to the model data **241** are specific parameters indicating properties of the specific component.

(67) In the vehicle **100** assumed in the model data **241**, vibration occurring in the internal combustion engine **10** and the automatic transmission **30** can be estimated based on the vehicle speed SP and the accelerator operation amount ACC. Further, the input torque Tin of the damper **15** can be estimated based on the vehicle speed SP and the accelerator operation amount ACC. Vibration occurring in the damper **15** can be estimated based on the input torque Tin, the rigidity value K of the damper, the hysteresis value H of the damper, and the gap value GA of the damper. The CPU **210** applies the vibration occurring in the internal combustion engine **10**, the automatic transmission **30**, and the damper **15** to the vehicle model **300** as vibration of the drive system **350**. The CPU **210** estimates, based on the values of the spring rates and the masses set in the vehicle model **300**, a transition of vibration of the frame **330** in a predetermined period as the transition of the vertical acceleration G of the vehicle **100**.

(68) The CPU **210** creates a power spectrum based on the estimated transition of the vertical acceleration G, and calculates a first power P**1** to a 20th power P**20** associated with the first frequency to the 20th frequency. The CPU **210** acquires, as a frequency FR, a frequency associated with a maximum power among the first power P**1** to the 20th power P**20**. The CPU **210** calculates a duration TA and a decrease rate DEC of vibration based on the estimated transition of the vertical acceleration G. The CPU **210** acquires, as a maximum acceleration GM, a maximum value of an absolute value of the vertical acceleration G acquired in the predetermined period. Details of the methods for calculating the first power P**1** to the 20th power P**20**, the frequency FR, the duration TA, the decrease rate DEC, and the maximum acceleration GM by the CPU **210** are the same as the details of the methods for calculating the individual values by the CPU **91**. Therefore, description of the methods is omitted.

(69) Next, description is given of training control for training the mapping M**1** defined by the mapping data **94**A of the controller **90**. In the following description, the simulator **200** and the controller **90** are connected by the external cable and communicable with each other.

(70) For example, when an operator gives an instruction to execute the training control, the CPU **210** executes the training control. The ROM **230** prestores a training program for executing the training control. The CPU **210** executes the training control by executing the training program stored in the ROM **230**.

(71) When the training control is started, a parameter set is input to the CPU **210** in Step S**61** of FIG. **7**. In this embodiment, the operator inputs numerical values of parameters by operating an input device connected to the simulator **200**. When the numerical values of all the parameters are input, a set of the parameters is input to the CPU **210** as the parameter set. Then, the CPU **210** advances the process to Step S**62**.

(72) In Step S**62**, the CPU **210** estimates vibration of the frame **330** of the vehicle model **300** as the transition of the vertical acceleration G of the vehicle **100** through simulation using the vehicle model **300** defined by the model data **241** in the storage **240**. Then, the CPU **91** advances the process to Step S**63**.

(73) In Step S**63**, the CPU **210** calculates characteristic variables based on the transition of the vertical acceleration G that is calculated in the process of Step S**62**. In this embodiment, the CPU **210** calculates a first power P**1** to a 20th power P**20**, a maximum acceleration GM, a frequency FR, a duration TA, and a decrease rate DEC as the characteristic variables related to vibration of the vehicle **100**. In this embodiment, the processes of Step S**61** to Step S**63** correspond to a simulation step. Then, the CPU **210** advances the process to Step S**64**.

(74) In Step S**64**, the CPU **210** links a determination label LA to the characteristic variables calculated in the process of Step S**63** based on the values of the condition parameters in the parameter set input in Step S**61**. The determination label LA indicates whether the damper **15** has

an abnormality. Specifically, the CPU **210** determines whether the following conditions are satisfied. The first condition is that the rigidity value K of the damper falls out of the predetermined normal range. The second condition is that the hysteresis value H of the damper falls out of the predetermined normal range. The third condition is that the gap value GA of the damper falls out of the predetermined normal range. When at least one of the three conditions is satisfied, the CPU **210** sets the determination label LA to, for example, a numerical value "1" indicating that the damper **15** has an abnormality. When none of the three conditions is satisfied, the CPU **210** sets the determination label LA to, for example, a numerical value "0" indicating that the damper **15** has no abnormality. In this embodiment, the determination label LA is the same type of variable as that of the abnormality determination variable, and can be set within a range of 0 to 1 similarly to the abnormality determination variable in the process of Step S**23**. Then, the CPU **210** advances the process to Step S**65**.

(75) In Step S**65**, the CPU **210** collects, into training data TRN, the characteristic variables calculated in Step S**63** and the vehicle speed SP and the accelerator operation amount ACC in the parameter set input when the characteristic variables are calculated. The CPU **210** sets, as teaching data TCH, the determination label LA associated with the characteristic variables. As illustrated in FIG. **6**, the CPU **210** outputs a set of the training data TRN and the teaching data TCH to the controller **90**.

(76) When the training data TRN and the teaching data TCH are input, the controller **90** executes a process of Step S**66**. In Step S**66**, the CPU **91** of the controller **90** updates the mapping M**1** of the mapping data **94**A in the storage **94** based on the input training data TRN and the input teaching data TCH.

(77) Specifically, the CPU **91** of the controller **90** sets the numerical values of the input training data TRN, that is, the first power P**1** to the 20th power P**20**, the maximum acceleration GM, the frequency FR, the duration TA, the decrease rate DEC, the vehicle speed SP, and the accelerator operation amount ACC as the input variable x(**1**) to the input variable x(**26**). Then, the CPU **91** updates the mapping M**1** by setting, as an output variable y(**1**), the determination label LA that is the teaching data TCH paired with the training data TRN. In this embodiment, the processes of Step S**65** and Step S**66** correspond to a training step. Then, the CPU **210** terminates the current training control.

(78) Actions of this embodiment are described. When the parameter set is input to the model data **241** of the simulator **200**, at least one of the condition parameters in the parameter set is set to a value outside the normal range, and the other condition parameters are set to values within the normal ranges. For example, the gap value GA of the damper **15** among the condition parameters is set outside the normal range, and the other condition parameters are set to values within the normal ranges. Therefore, the simulator **200** outputs characteristic variables under the assumption that the gap value GA is an abnormal value because the components of the damper **15** are worn out. When the parameter set is input to the model data **241**, all the condition parameters in the parameter set are set to values within the normal ranges. At this time, at least one of the condition parameters is set to a value that falls within the normal range but is close to a boundary between the normal range and the abnormal range. Therefore, the simulator **200** outputs characteristic variables under the assumption that the damper **15** is near the boundary between the normal state and the abnormal state. By inputting an arbitrary parameter set to the simulator **200** as described above, various characteristic variables are obtained assuming a state of the damper **15** that is desired by the operator.

(79) Effects of this embodiment are described.

(80) (1) According to the embodiment described above, the characteristic variables under the assumption that the damper **15** has an abnormality can be obtained such that the operator inputs the parameter set to the simulator **200**. A large number of characteristic variables can be obtained by changing the values of the condition parameters in the parameter set as appropriate. Therefore,

characteristic variables variously assuming, for example, the abnormality levels of the damper **15** can be obtained even if the abnormality of the damper **15** occurs at a low frequency to provide only a few opportunities to obtain characteristic variables in the event of actual abnormalities of the damper **15**. The mapping M**1** is updated by using the obtained characteristic variables as the training data TRN, thereby increasing a probability that the mapping M**1** can output an appropriate output variable.

(81) (2) According to the embodiment described above, the value that falls within the normal range but is close to the boundary between the normal range and the abnormal range is input to the simulator **200** as the condition parameter. Therefore, it is possible to obtain characteristic variables under the assumption that the damper **15** is becoming abnormal. The characteristic variables when the damper **15** is near the boundary between the normal state and the abnormal state are very important from the viewpoint of improving the accuracy of the output variable of the mapping M**1**. When the damper **15** remains in the normal range but is becoming abnormal, there is a low possibility that a problem such as vibration emerges, thereby reducing opportunities to acquire data. In the embodiment described above, it is possible to easily obtain the characteristic variables that are hardly acquired as data but are important for the update of the mapping M**1**.

(82) (3) In the embodiment described above, the damper **15** is an abnormality determination target component for the mapping M**1** among the components on the power transmission path from the internal combustion engine **10** to the driving wheels **69**. The damper **15** has components such as the damper body **16** and the attenuator **17**, which may be related to vibration of the vehicle **100**. Further, the damper **15** receives a relatively large torque from the internal combustion engine **10**. It is particularly appropriate to improve the accuracy of the output variable of the mapping M**1** by using the simulator **200** for the damper **15**.

(83) (4) In the embodiment described above, the condition parameters include the specific parameter such as the rigidity value K indicating the property of the damper **15**. The specific parameter indicating the property of the damper **15** has the normal range preset when input to the simulator **200**. Thus, the abnormal state of the damper **15** can securely be reflected by inputting a value outside the normal range to the simulator **200** as the specific parameter indicating the property of the damper **15**.

(84) (5) In the embodiment described above, the damper **15** has the damper body **16** and the attenuator **17** having elastic members. Therefore, when the damper **15** has an abnormality, there is a strong possibility that the vibration of the vehicle **100** increases. That is, there is a strong possibility that the presence or absence of the abnormality of the damper **15** is related to the magnitude of the vibration of the vehicle **100**. In the embodiment described above, the simulator **200** outputs, as the characteristic variable, the maximum acceleration GM that reflects the magnitude of the vibration of the vehicle **100**, and the mapping M**1** is updated based on the maximum acceleration GM. When the damper **15** has an abnormality, not only the magnitude of the vibration of the vehicle **100** but also a frequency characteristic of the vibration may change. In the embodiment described above, the simulator **200** outputs, as the first power P**1** to the 20th power P**20**, the power spectrum that reflects the frequency characteristic of the vibration, and the mapping M**1** is updated based on the power spectrum. The training effect of the mapping M**1** using the simulator **200** is increased by updating the mapping M**1** by using the parameters related to the presence or absence of the abnormality of the damper **15**.

(85) (6) The damper body **16** of the damper **15** has the elastic member. When the elastic member has an abnormality, the resonance frequency of the damper **15** changes, thereby increasing a possibility of a change in the frequency FR at the maximum amplitude of the vibration caused by the damper **15**. In the embodiment described above, the simulator **200** outputs, as the characteristic variable, the frequency FR particularly related to the abnormality of the damper body **16**, and the mapping M**1** is updated based on the frequency FR. The training effect of the mapping M**1** is increased particularly about the presence or absence of the abnormality of the damper body **16**.

(86) (7) The damper **15** has the attenuator **17**. When the attenuator **17** has an abnormality, there is a strong possibility of a change in the duration TA and the decrease rate DEC of the vibration of the damper **15**. In the embodiment described above, the simulator **200** outputs, as the characteristic variables, the duration TA and the decrease rate DEC particularly related to the abnormality of the attenuator **17**, and the mapping M**1** is updated based on the duration TA and the decrease rate DEC. The training effect of the mapping M**1** is increased particularly about the presence or absence of the abnormality of the attenuator **17**.

(87) (8) In the embodiment described above, the rotation speeds of the input shaft and the output shaft of the damper **15** change when the vehicle speed SP changes. Even in the same state of the damper **15**, the vibration caused by the damper **15** may vary depending on the magnitude of the vehicle speed SP. In the embodiment described above, the vehicle speed SP is employed as one of the condition parameters to be input to the model data **241**, and the simulator **200** calculates the characteristic variables based on the vehicle speed SP. Thus, there is a greater expectation that the simulator **200** outputs accurate characteristic variables.

(88) (9) In the embodiment described above, when the accelerator operation amount ACC changes, the load on the internal combustion engine **10** changes and the torque input to the damper **15** changes as well. Even in the same state of the damper **15**, the vibration caused by the damper **15** may vary depending on the magnitude of the accelerator operation amount ACC. In the embodiment described above, the accelerator operation amount ACC is employed as one of the condition parameters to be input to the model data **241**, and the simulator **200** calculates the characteristic variables based on the accelerator operation amount ACC. Thus, there is a greater expectation that the simulator **200** outputs accurate characteristic variables.

OTHER EMBODIMENTS

(89) This embodiment may be modified as follows. This embodiment and the following modified examples may be combined without causing any technical contradiction.

(90) Characteristic Variables

(91) In the embodiment described above, the characteristic variables related to the vibration of the vehicle **100** are employed, but characteristic variables related to noise of the vehicle **100** may be employed as well. In an example illustrated in FIG. **8**, the vehicle **100** includes a microphone **75** in addition to the components of the embodiment described above. For example, the microphone **75** is located in the vehicle cabin. The microphone **75** detects a sound wave in a frequency band perceivable by humans as noise, such as 20 Hz or higher and 20 kHz or lower. A signal is input to the controller **90** from the microphone **75**.

(92) Similarly to the embodiment described above, the CPU **91** of the controller **90** calculates a first power P**1** to a 20th power P**20**, a frequency FR, a duration TA, and a decrease rate DEC based on a sound wave in a predetermined period that is detected by the microphone **75**. The controller **90** acquires a maximum amplitude of the sound wave in the predetermined period. The CPU **91** inputs the first power P**1** to the 20th power P**20**, the maximum amplitude, the frequency FR, the duration TA, the decrease rate DEC, a vehicle speed SP, and an accelerator operation amount ACC to the mapping M**1** as the input variable x(**1**) to the input variable x(**26**).

(93) When a parameter set is input to the model data **241**, the CPU **210** of the simulator **200** estimates vibration of the drive system **350** of the vehicle model **300**. At this time, the CPU **210** estimates vibration in the frequency band of 20 Hz or higher and 20 kHz or lower. Although the acceleration sensor or the like has difficulty in detecting the vibration in this frequency band because the frequency is high and the amplitude is small, the calculation in the CPU **210** can yield the vibration. The CPU **210** applies the vibration of the drive system **350** to the vehicle model **300** to estimate vibration of the frame **330**. The CPU **210** handles the vibration of the frame **330** as a sound wave generated by the vehicle **100**, and calculates a first power P**1** to a 20th power P**20**, a maximum amplitude, a frequency FR, a duration TA, and a decrease rate DEC as characteristic variables related to noise.

(94) As described above, the vibration and the noise of the vehicle **100** generally have the same characteristics though the target frequency bands differ from each other. Thus, the same type of technology as that of the embodiment described above can be employed even in the case where the characteristic variables related to the noise of the vehicle **100** are employed as in this modified example.

(95) In the embodiment described above, the characteristic variables may be changed. For example, the number of predetermined frequencies for the calculation of the powers associated with the frequencies based on the power spectrum is not limited to 20, but may be 19 or less or more than 20. To accurately grasp a characteristic of vibration in a wide frequency band by using the power spectrum, the number of frequencies is preferably large to some extent. If a frequency is identified for vibration that changes depending on whether the damper **15** has an abnormality, it is only necessary to calculate at least a power associated with this frequency.

(96) For example, a variable indicating a power spectrum density in a predetermined specific frequency band may be employed as the characteristic variable. As a specific example, the CPU **91** may calculate, from the vibration power spectrum, a total of 20 power densities associated with a predetermined first frequency band to a predetermined 20th frequency band as a first power density PA**1** to a 20th power density PA**20** in order from the first frequency band. The CPU **91** may use the first power density PA**1** to the 20th power density PA**20** as the characteristic variables.

(97) For example, an average of the absolute values of the vertical accelerations G acquired in the predetermined period may be used as the characteristic variable. In this case, the average of the absolute values of the vertical accelerations G acquired in the predetermined period is a variable indicating an acceleration of the vehicle **100**.

(98) For example, all of the first power P**1** to the 20th power P**20**, the maximum acceleration GM, the frequency FR, the duration TA, and the decrease rate DEC need not essentially be used as the characteristic variables. Any type of characteristic variable and any number of characteristic variables may be employed as long as at least one characteristic variable related to the vibration or the noise of the vehicle **100** is employed.

(99) Parameter Set

(100) In the embodiment described above, the parameter set may be changed. Depending on, for example, the structure of the damper **15**, the numerical value of a part of the rigidity value K of the damper, the hysteresis value H of the damper, and the gap value GA of the damper has a low possibility of actually falling out of the normal range. In this case, the part of the rigidity value K of the damper, the hysteresis value H of the damper, and the gap value GA of the damper may be omitted from the parameter set and may be set to a fixed value that eliminates the need to input the numerical value. In the training control for the mapping M**1** for determining whether the damper **15** has an abnormality, it is only necessary to employ at least one of the rigidity value K of the damper, the hysteresis value H of the damper, and the gap value GA of the damper.

(101) For example, the vehicle speed SP and the accelerator operation amount ACC may be omitted from the parameter set to be input to the model data **241** of the simulator **200**. That is, the parameter set may have only the specific parameters indicating the properties of the damper **15**. In the case where the vehicle speed SP and the accelerator operation amount ACC are omitted from the parameter set, it is appropriate to handle the vehicle speed SP and the accelerator operation amount ACC as predetermined constant values in the vehicle model **300**.

(102) Determination Label

(103) The determination label may be set to a value that changes in a range from "0" to "1" instead of being set to "0" or "1". For example, when the rigidity value K of the damper falls out of the normal range, the determination label may be set closer to "1" as the rigidity value K of the damper is further away from the boundary between the normal range and the abnormal range.

(104) Abnormality Determination Variable

(105) The threshold related to the abnormality determination variable may be changed as

appropriate. For example, the accuracy of determination that an abnormality occurs increases as the threshold is made closer to "1". However, this setting increases such an adverse effect that the abnormality cannot be determined even though the abnormality actually occurs.

(106) Simulation Step

(107) In the embodiment described above, the simulation step may be changed. For example, in Step S**61**, the operator need not essentially input arbitrary values as the parameters. Instead, the CPU **210** may randomly set the parameters.

(108) Training Step

(109) In the embodiment described above, the controller **90** of the vehicle **100** executes the training step, but another apparatus such as the simulator **200** may execute the training step. For example, it is appropriate that the mapping data **94**A updated by the simulator **200** be applied to the controller **90** of each vehicle **100**.

(110) The values of the vehicle speed SP and the accelerator operation amount ACC contained in the training data TRN need not essentially be equal to the values of the vehicle speed SP and the accelerator operation amount ACC input to the model data **241** when the characteristic variables are calculated.

(111) Input Variables

(112) In the embodiment described above, the input variables of the mapping M**1** may be changed. For example, in the case where the characteristic variables are changed as described above, it is appropriate that the input variables be variables to be used as the characteristic variables among the first power P**1** to the 20th power P**20**, the maximum acceleration GM, the frequency FR, the duration TA, and the decrease rate DEC.

(113) Output Variable

(114) In the embodiment described above, the output variable of the mapping M**1** may be changed. For example, the number of output variables of the mapping M**1** need not be one, but may be plural. As a specific example, the output variables of the mapping M**1** may be a variable indicating a possibility that the damper body **16** has an abnormality, and a variable indicating a possibility that the attenuator **17** has an abnormality. In the case where a plurality of output variables is output, abnormalities may be reported in the following manner. That is, the possibilities of the abnormalities may be reported individually. Alternatively, an abnormality having the strongest possibility may be reported alone.

(115) Specific Component

(116) In the embodiment described above, the specific component is not limited to the damper **15**. For example, teeth of a gear of the automatic transmission **30** may be worn out or partially chipped due to deterioration of the gear over time. In this case, the vehicle **100** may generate vibration or noise due to the abnormality of the gear of the automatic transmission **30**. Similarly, the vehicle **100** may generate vibration or noise due to an abnormality of a gear of the power split device **20**. If a model capable of calculating characteristic variables related to the vibration or noise can be derived for the automatic transmission **30** or the power split device **20** based on, for example, a gap value between the gears and physical property values of the gears, the technology of the embodiment described above can be applied to training of mapping for determining the abnormality of the automatic transmission **30** or the power split device **20**. In this case, the automatic transmission **30** and the power split device **20** are specific components on the power transmission path from the internal combustion engine **10** serving as the drive source of the vehicle **100** to the driving wheels **69**. The same applies to the first motor generator **61** and the second motor generator **62**.

(117) The technology for training the mapping in the embodiment described above may be applied to a component that is not located on the power transmission path from the drive source of the vehicle **100** to the driving wheels **69**. For example, when the oil pump **66** has an abnormality, the vehicle **100** may generate vibration or noise. If a model capable of calculating characteristic

variables related to the vibration or noise can be derived for the oil pump **66** based on specific parameters related to the properties of the oil pump **66**, the technology of the embodiment described above can be applied to training of mapping for determining the abnormality of the oil pump **66**.

(118) Mapping

(119) In the embodiment described above, the activation function of the mapping is illustrative, and may be changed.

(120) In the embodiment described above, the neural network having one intermediate layer is exemplified as the neural network, but the neural network may have two or more intermediate layers.

(121) In the embodiment described above, the fully connected feedforward neural network is exemplified as the neural network. The present disclosure is not limited to this case. For example, the neural network may be a recurrent neural network.

(122) In the embodiment described above, the function approximate device serving as the mapping is not limited to the neural network. For example, the function approximate device may be a regression equation having no intermediate layer.

(123) Controller and Simulator

(124) In the embodiment described above, the controller **90** is not limited to the device that includes the CPU **91** and the ROM **93** and executes the software process. As a specific example, the controller **90** may include a dedicated hardware circuit such as an application-specific integrated circuit (ASIC) configured to execute a hardware process in place of at least a part of the software process in the embodiment described above. That is, the controller **90** may have one of the following structures (a) to (c).

(125) (a) The controller **90** includes a processor configured to execute all the processes described above based on programs, and a program storage such as a ROM that stores the programs.

(126) (b) The controller **90** includes a processor configured to execute a part of the processes described above based on programs, a program storage, and a dedicated hardware circuit configured to execute the remaining processes.

(127) (c) The controller **90** includes a dedicated hardware circuit configured to execute all the processes described above.

(128) A plurality of devices or circuits may be provided as the software execution device including the processor and the program storage or as the dedicated hardware circuit. The same applies to the simulator **200**.

(129) Sensors

(130) In the embodiment described above, the sensors of the vehicle **100** may be changed. For example, the vibration of the vehicle **100** due to the abnormality of the damper **15** may occur as vibration in a longitudinal direction of the vehicle **100** or vibration in a vehicle width direction of the vehicle **100**. In this case, an acceleration sensor configured to detect an acceleration in the longitudinal direction of the vehicle **100** or an acceleration sensor configured to detect an acceleration in the vehicle width direction of the vehicle **100** may be employed in place of or in addition to the acceleration sensor **74**.

(131) Vehicle

(132) In the embodiment described above, a so-called series-parallel hybrid vehicle is exemplified as the vehicle. The present disclosure is not limited to this case. For example, the vehicle may be a series hybrid vehicle or a parallel hybrid vehicle.

(133) In the embodiment described above, the vehicle is not limited to the vehicle including the internal combustion engine and the motor generator. For example, the vehicle may have the internal combustion engine but need not have the motor generator. For example, the vehicle may have the motor generator but need not have the internal combustion engine.

Claims

1. A training method for training a mapping that outputs, as an output variable, an abnormality determination variable that (i) indicates an occurrence possibility of an abnormality of a specific component mounted on a vehicle and (ii) is used in a determination process for determining whether or not the specific component has the abnormality, the method comprising: outputting, by a simulator and based on an input parameter set to the simulator that has a plurality of condition parameters related to conditions of the vehicle, characteristic variables at least one of which indicates a decrease rate of at least one of (i) vibration of the vehicle per unit time and (ii) noise of the vehicle per unit time, the simulator storing model data that defines a vehicle model, which is a model of structure of the vehicle, and outputting the characteristic variables by inputting the input parameter set to the model data, one of the condition parameters being a specific parameter indicating a property of the specific component, and the input parameter set (i) indicating that the specific component is presumed to have the abnormality in advance by (ii) being a parameter set having the specific parameter that falls outside of a predetermined normal range; and updating, by a processor, the mapping based on training data and teaching data, the training data including a plurality of input variables for stored mapping data defining the mapping, the input variables including the characteristic variables output by the simulator, and the teaching data including the abnormality determination variable indicating that the specific component has the abnormality, wherein: the decrease rate is calculated (i) by subtracting an amplitude of the vibration or noise at an end of a duration of the amplitude or noise from an amplitude of the vibration or noise at a start of the duration and (ii) by dividing a value obtained through the subtraction by the duration; the specific component is a damper comprising a damper body, which includes an elastic member, and an attenuator; and the characteristic variables based upon which the mapping is updated include (i) a frequency of the damper at a maximum amplitude of vibration that is caused by the damper and is related to an abnormality of the damper body, (ii) a duration of vibration of the damper that is related to an abnormality of the attenuator, and (iii) a decrease rate of the vibration that is related to the abnormality of the attenuator.
2. The method according to claim 1, wherein one of the condition parameters is a vehicle speed.
3. The method according to claim 1, wherein one of the condition parameters is an operation amount of an accelerator pedal.
4. The method according to claim 1, wherein the structure of the vehicle modeled by the vehicle model includes a driving wheel, a suspension, a frame, a mount, and a drive system of the vehicle.