(12) UK Patent (19) GB (11) 2574392 (13) B

(45) Date of B Publication 06.01.2021

(54) Title of the Invention: An apparatus and a method for controlling steering of rear wheels of a vehicle

(51) INT CL: ***B62D 7/15*** (2006.01) ***B60W 30/045*** (2012.01) ***B60W 30/18*** (2012.01) ***B62D 6/00*** (2006.01)

(21) Application No: **1808998.7**

(22) Date of Filing: **01.06.2018**

(43) Date of A Publication **11.12.2019**

(56) Documents Cited:
GB 2527100 A
GB 2523085 A
GB 2492655 A
JP 2006021563 A
JP H06298109
JP H03262782

(58) Field of Search:
As for published application 2574392 A viz:
INT CL **B60W, B62D**
Other: **EPODOC, WPI, Internet, Patent Fulltext**
updated as appropriate

Additional Fields
Other: **None**

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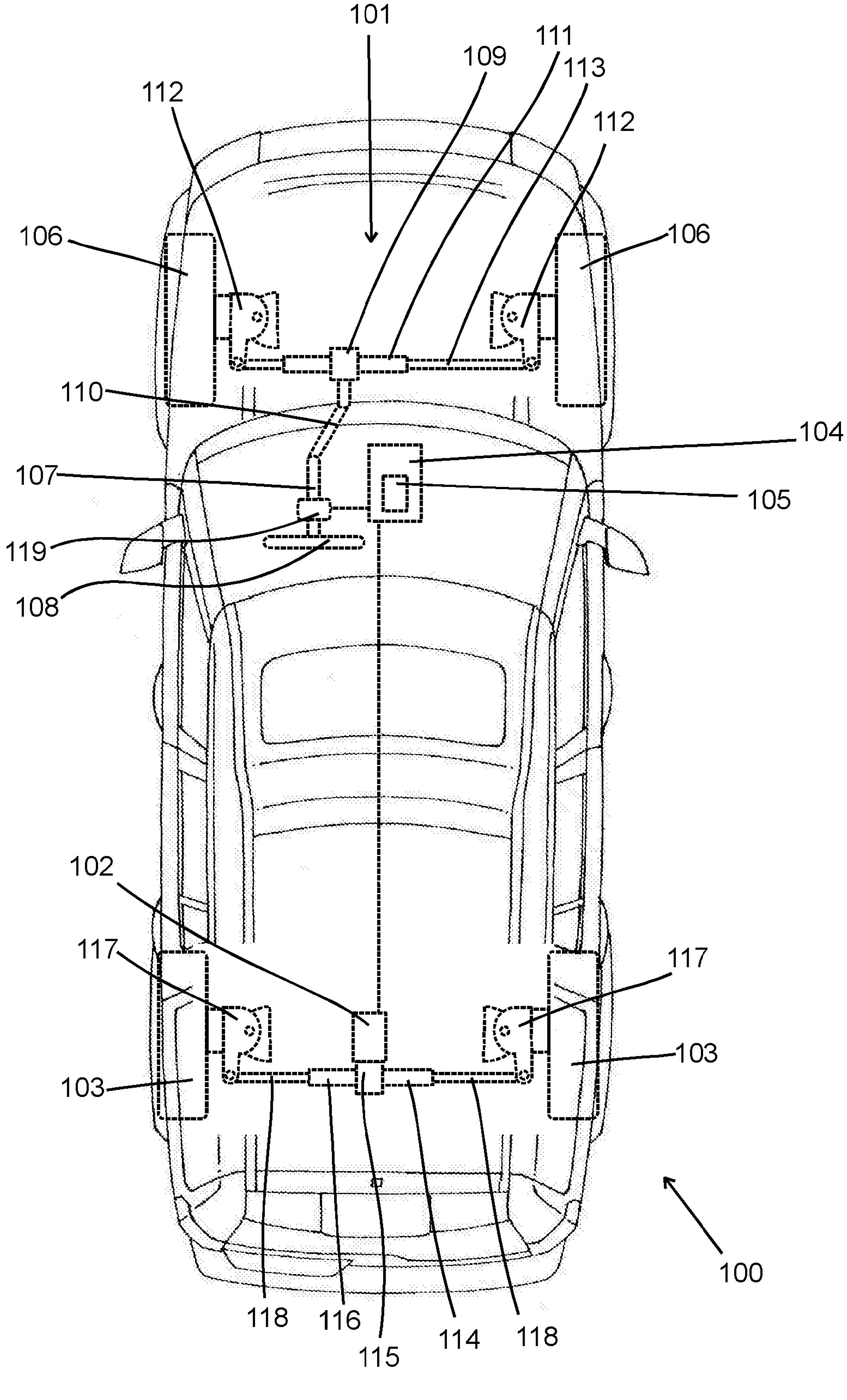
GB 2574392 B



101
109
111
113
112
112
106
106
110
104
107
105
119
108
102
117
117
103
103
118
116
115
114
118
100

Fig. 1

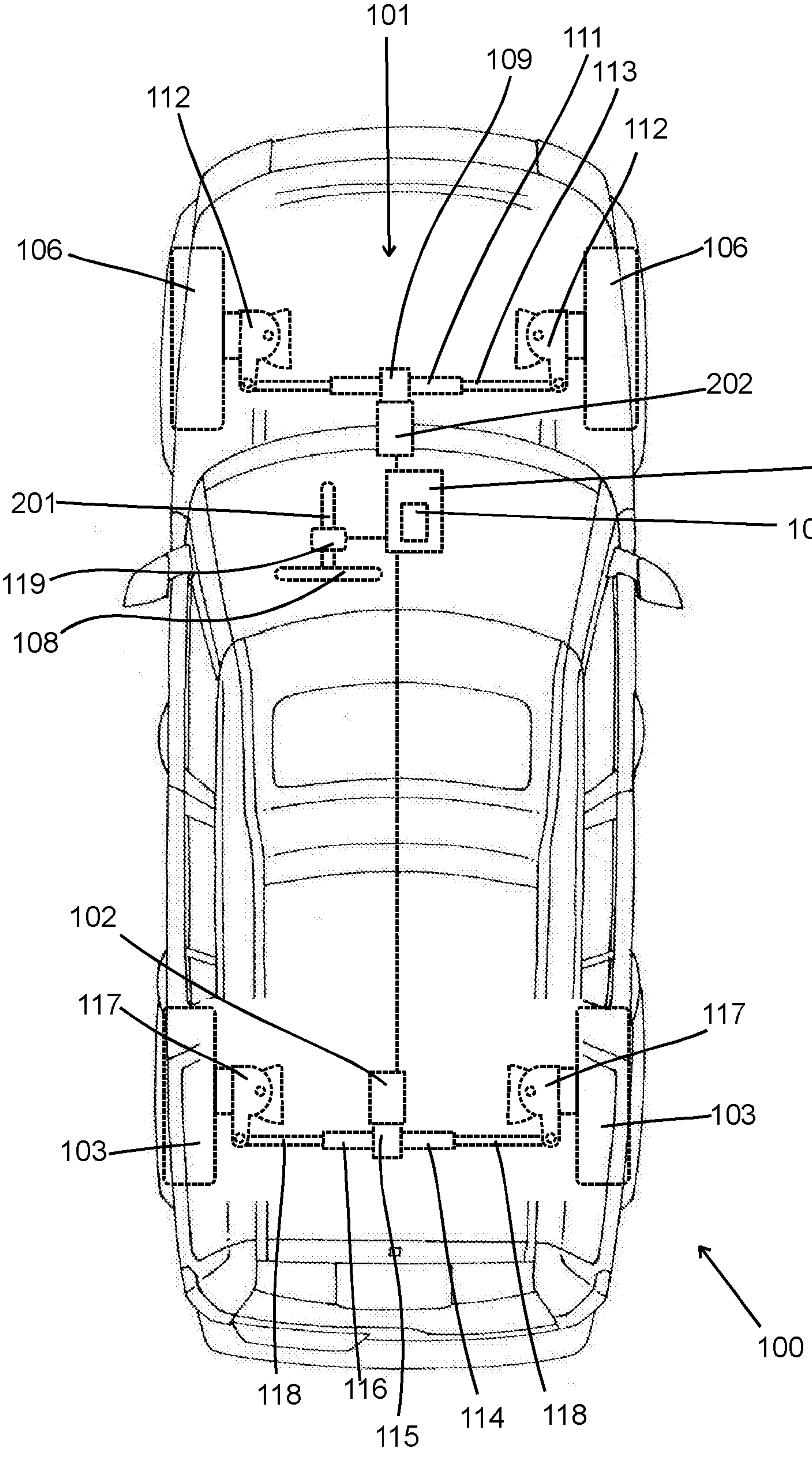

101
109
111
113
112
112
106
106
202
104
201
105
119
108
102
117
117
103
103
100
118
116
115
114
118

Fig. 2

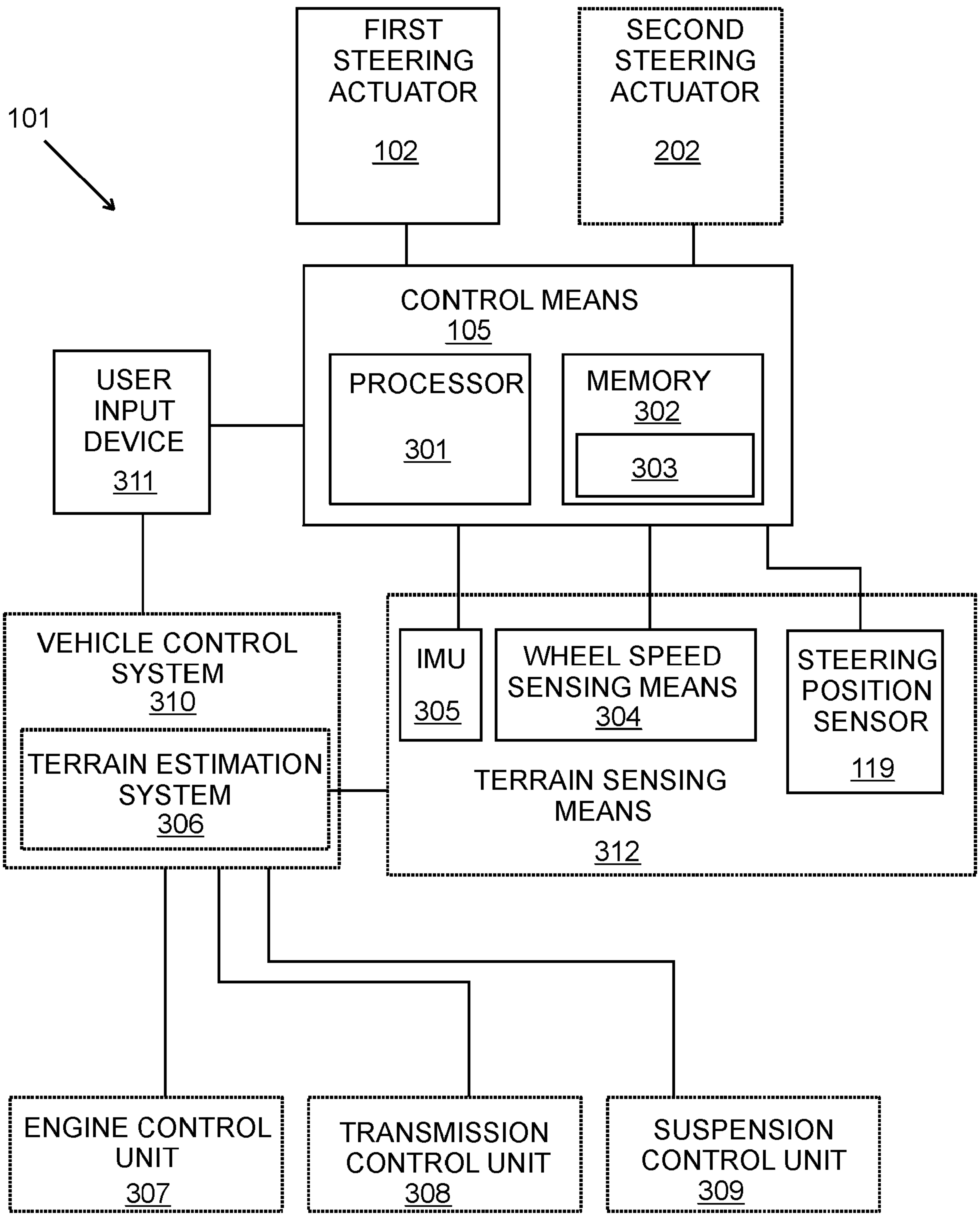

101
FIRST STEERING ACTUATOR 102
SECOND STEERING ACTUATOR 202
CONTROL MEANS 105
PROCESSOR 301
MEMORY 302
303
USER INPUT DEVICE 311
VEHICLE CONTROL SYSTEM 310
TERRAIN ESTIMATION SYSTEM 306
IMU 305
WHEEL SPEED SENSING MEANS 304
STEERING POSITION SENSOR 119
TERRAIN SENSING MEANS 312
ENGINE CONTROL UNIT 307
TRANSMISSION CONTROL UNIT 308
SUSPENSION CONTROL UNIT 309

Fig. 3

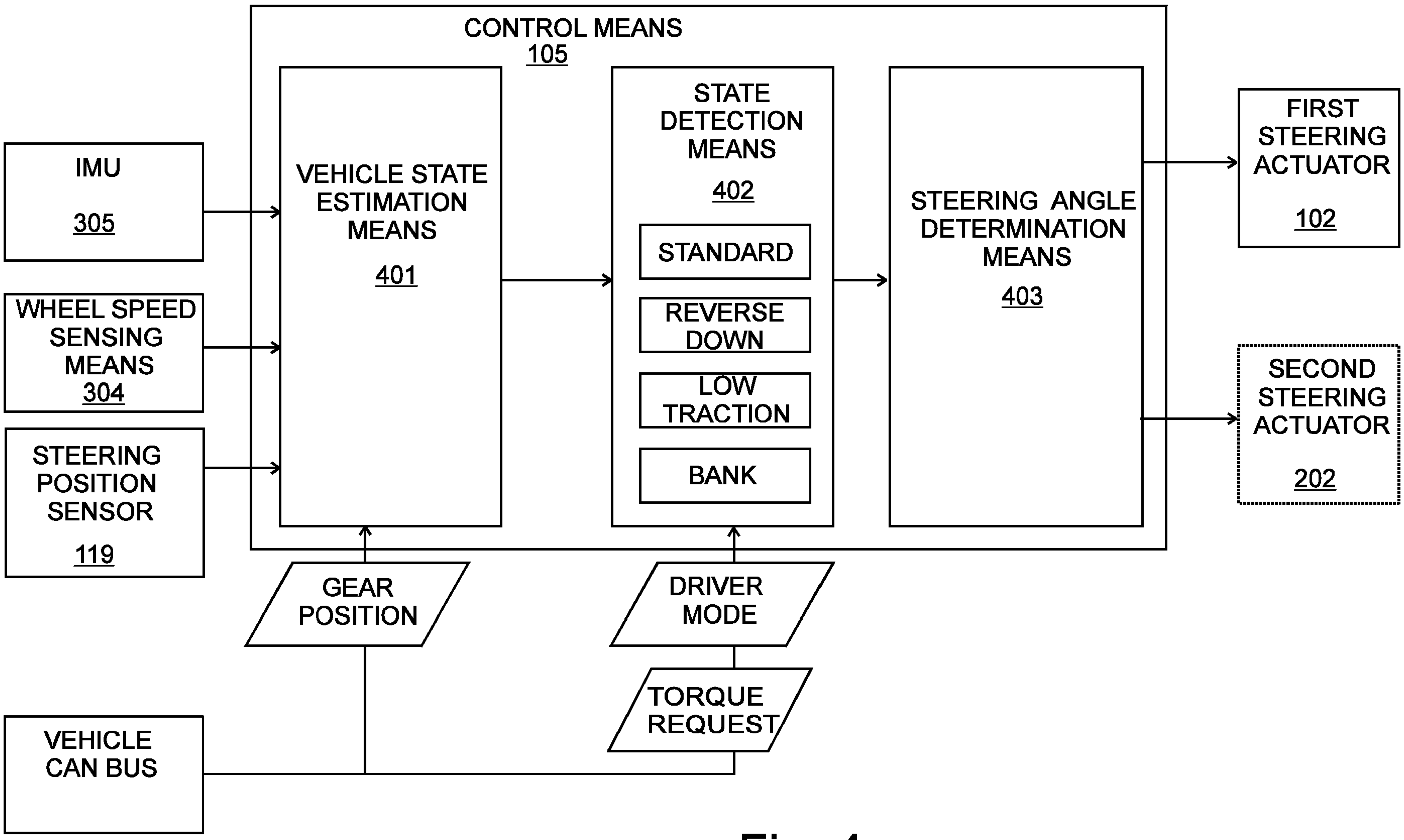

CONTROL MEANS
105
IMU
305
WHEEL SPEED
SENSING
MEANS
304
STEERING
POSITION
SENSOR
119
VEHICLE STATE
ESTIMATION
MEANS
401
STATE
DETECTION
MEANS
402
STANDARD
REVERSE
DOWN
LOW
TRACTION
BANK
STEERING ANGLE
DETERMINATION
MEANS
403
FIRST
STEERING
ACTUATOR
102
SECOND
STEERING
ACTUATOR
202
GEAR
POSITION
DRIVER
MODE
TORQUE
REQUEST
VEHICLE
CAN BUS

Fig. 4

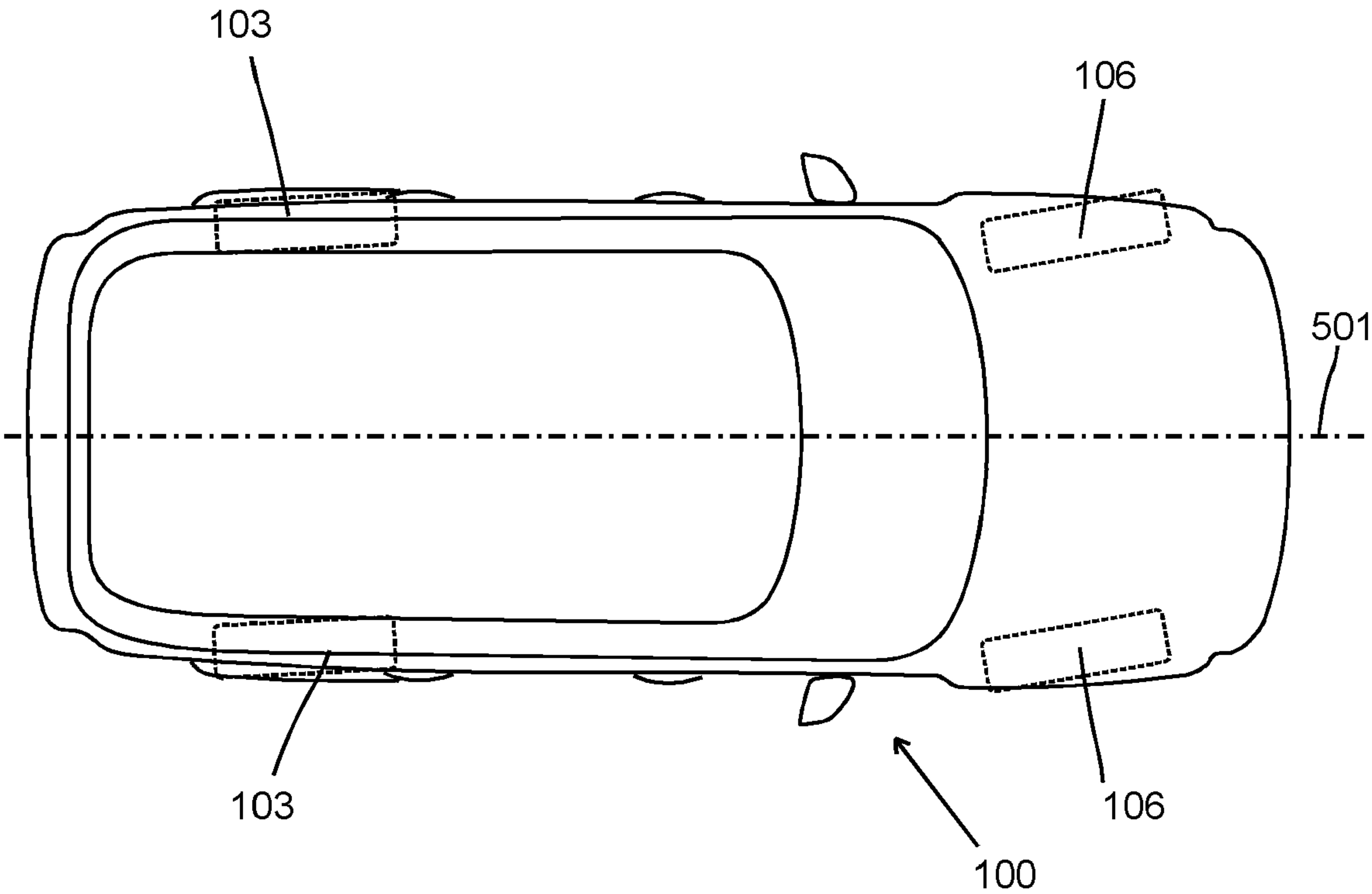


Fig. 5

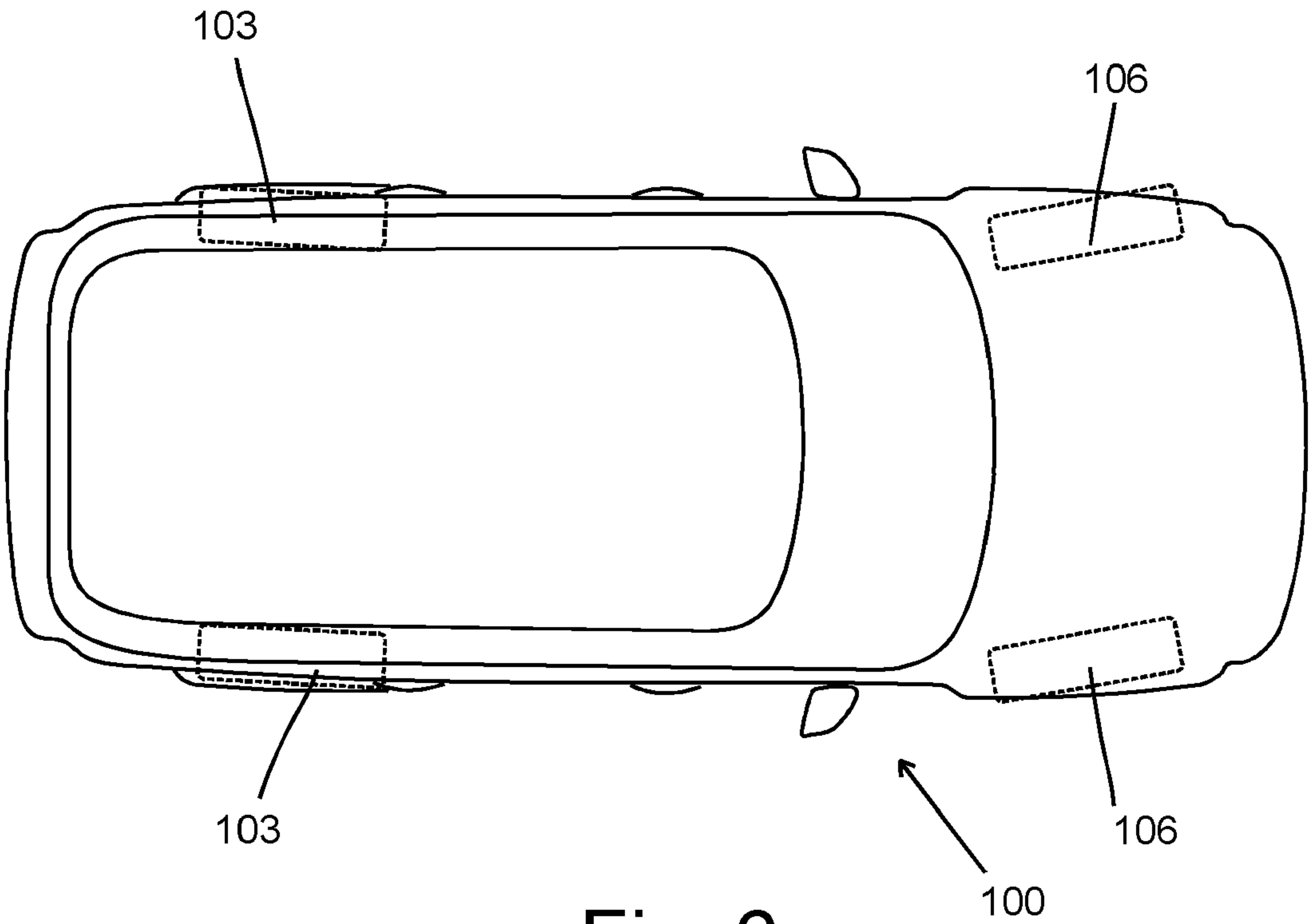


Fig. 6

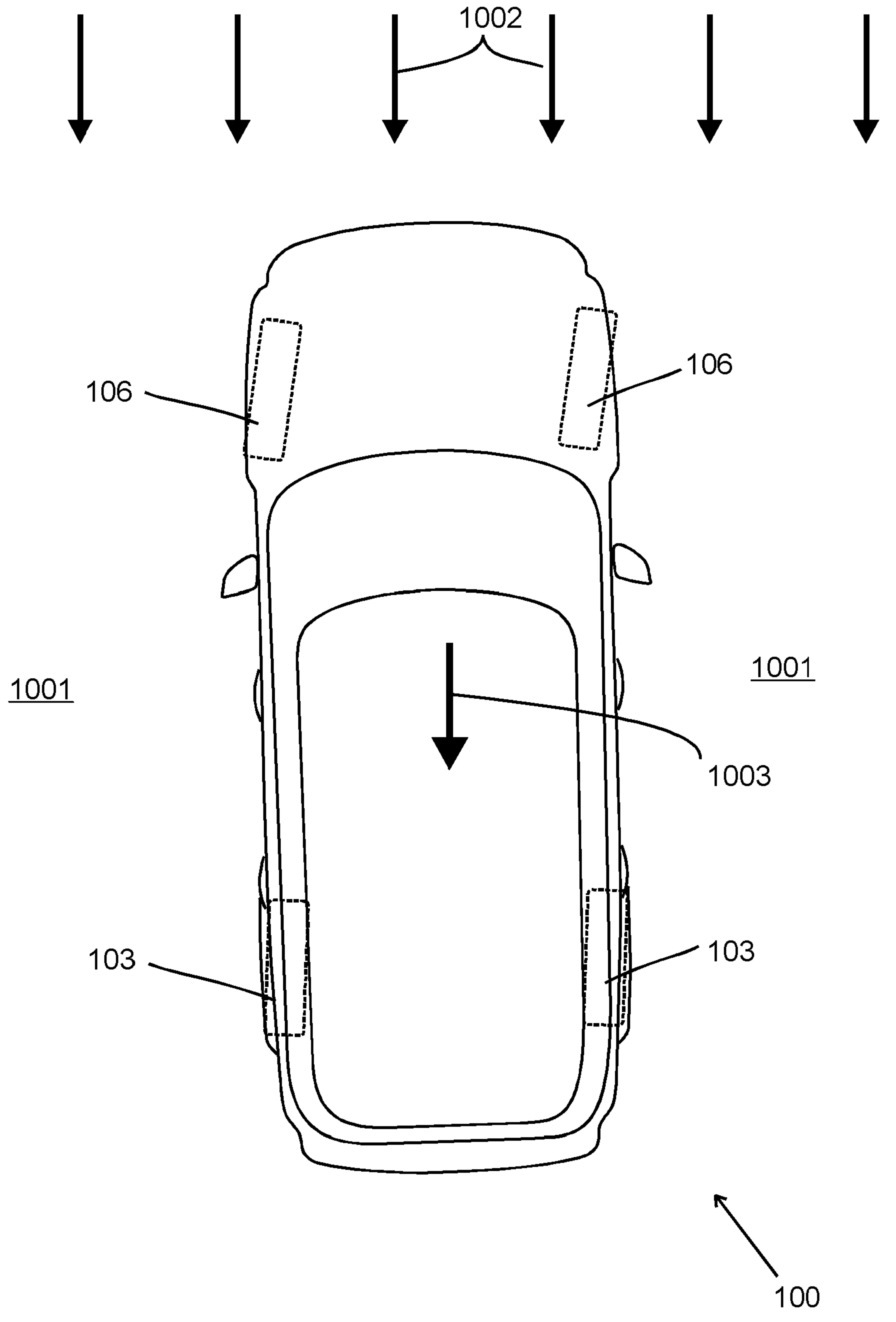


Fig. 7

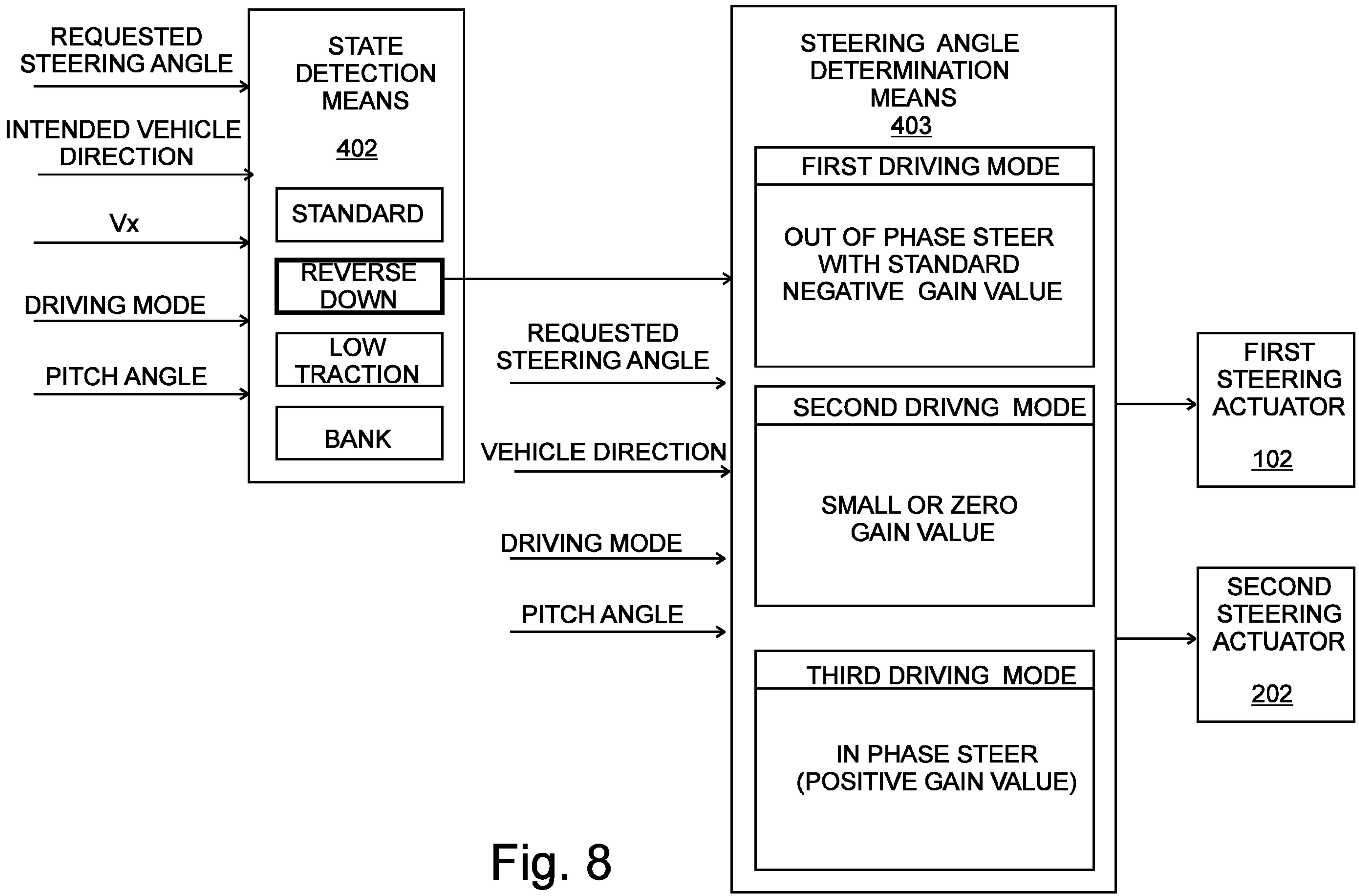

REQUESTED STEERING ANGLE
INTENDED VEHICLE DIRECTION
Vx
DRIVING MODE
PITCH ANGLE
STATE DETECTION MEANS
402
STANDARD
REVERSE DOWN
LOW TRACTION
BANK
REQUESTED STEERING ANGLE
VEHICLE DIRECTION
DRIVING MODE
PITCH ANGLE
STEERING ANGLE DETERMINATION MEANS
403
FIRST DRIVING MODE
OUT OF PHASE STEER WITH STANDARD NEGATIVE GAIN VALUE
SECOND DRIVNG MODE
SMALL OR ZERO GAIN VALUE
THIRD DRIVING MODE
IN PHASE STEER (POSITIVE GAIN VALUE)
FIRST STEERING ACTUATOR
102
SECOND STEERING ACTUATOR
202

Fig. 8

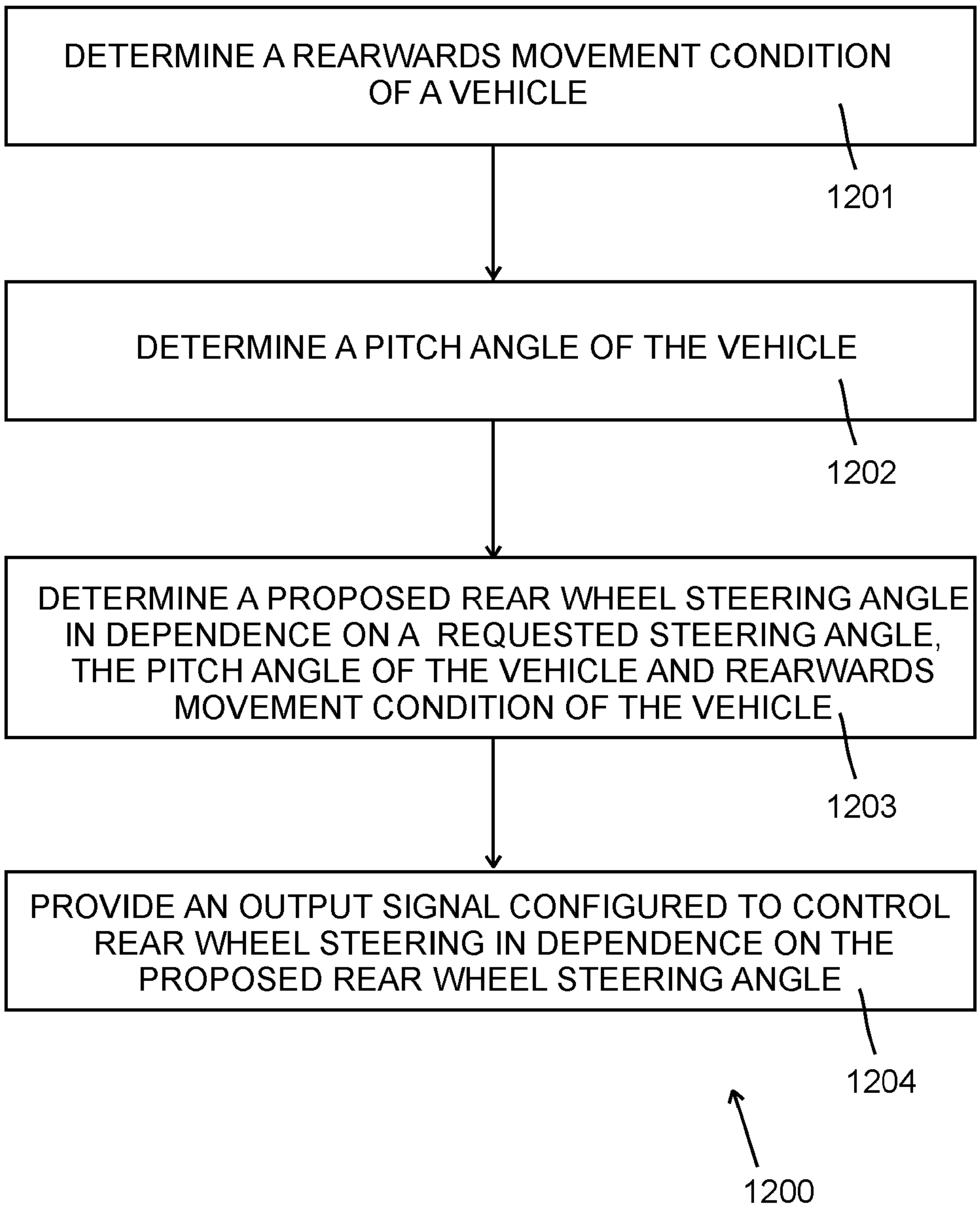

DETERMINE A REARWARDS MOVEMENT CONDITION OF A VEHICLE
1201
DETERMINE A PITCH ANGLE OF THE VEHICLE
1202
DETERMINE A PROPOSED REAR WHEEL STEERING ANGLE IN DEPENDENCE ON A REQUESTED STEERING ANGLE, THE PITCH ANGLE OF THE VEHICLE AND REARWARDS MOVEMENT CONDITION OF THE VEHICLE
1203
PROVIDE AN OUTPUT SIGNAL CONFIGURED TO CONTROL REAR WHEEL STEERING IN DEPENDENCE ON THE PROPOSED REAR WHEEL STEERING ANGLE
1204
1200

Fig. 9

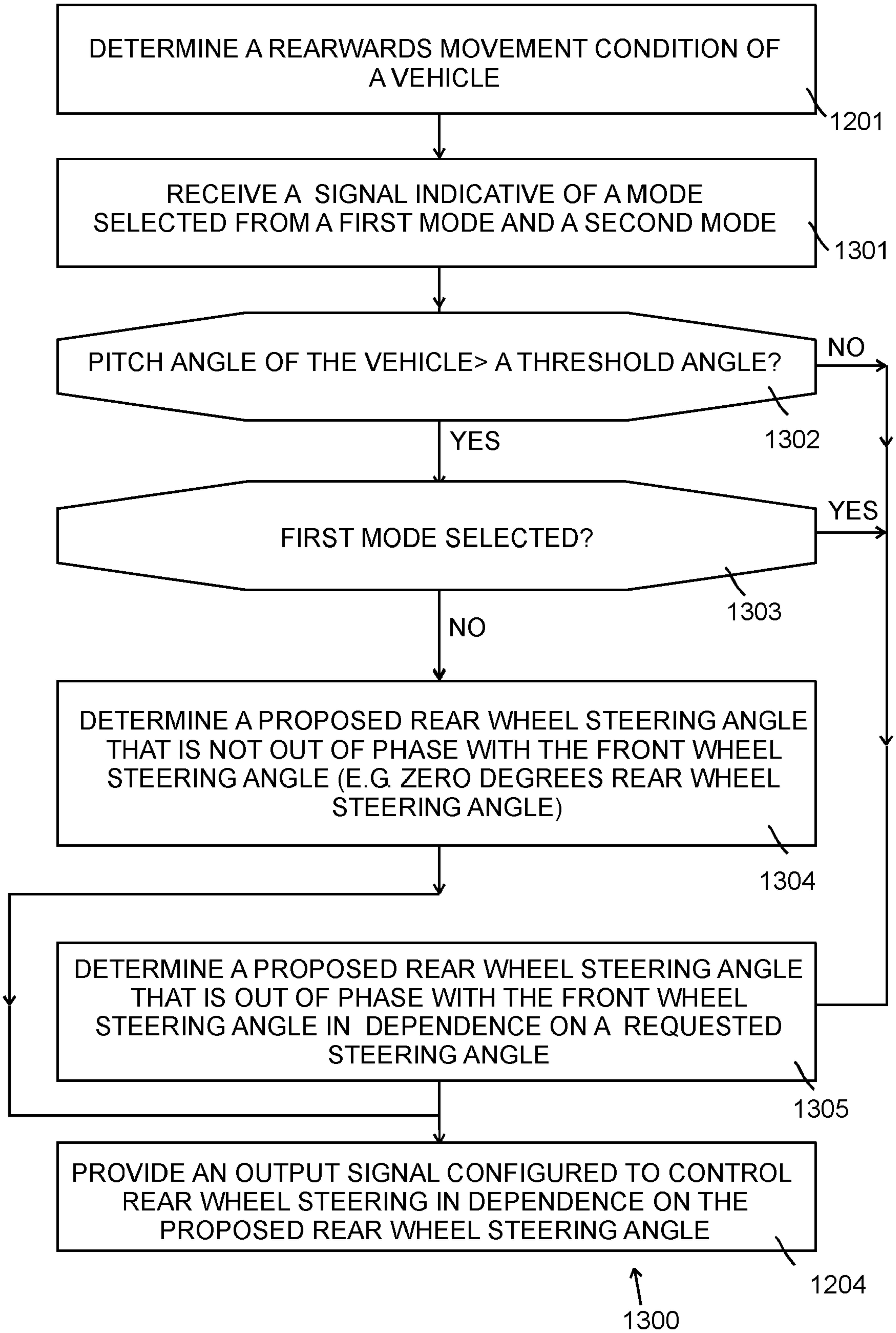

DETERMINE A REARWARDS MOVEMENT CONDITION OF A VEHICLE
1201
RECEIVE A SIGNAL INDICATIVE OF A MODE SELECTED FROM A FIRST MODE AND A SECOND MODE
1301
PITCH ANGLE OF THE VEHICLE> A THRESHOLD ANGLE?
NO
YES
1302
FIRST MODE SELECTED?
YES
NO
1303
DETERMINE A PROPOSED REAR WHEEL STEERING ANGLE THAT IS NOT OUT OF PHASE WITH THE FRONT WHEEL STEERING ANGLE (E.G. ZERO DEGREES REAR WHEEL STEERING ANGLE)
1304
DETERMINE A PROPOSED REAR WHEEL STEERING ANGLE THAT IS OUT OF PHASE WITH THE FRONT WHEEL STEERING ANGLE IN DEPENDENCE ON A REQUESTED STEERING ANGLE
1305
PROVIDE AN OUTPUT SIGNAL CONFIGURED TO CONTROL REAR WHEEL STEERING IN DEPENDENCE ON THE PROPOSED REAR WHEEL STEERING ANGLE
1204
1300

Fig. 10

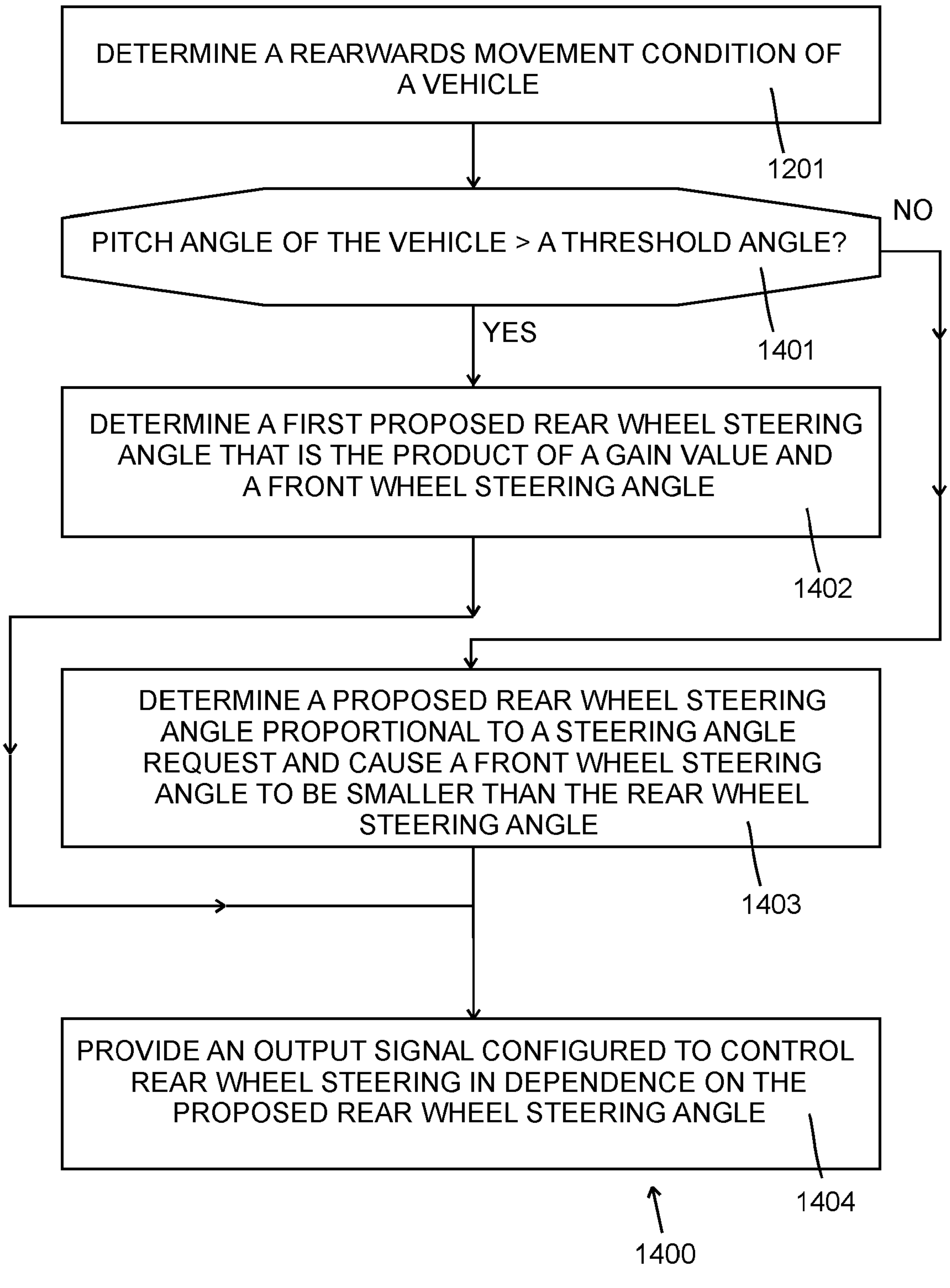

DETERMINE A REARWARDS MOVEMENT CONDITION OF A VEHICLE
1201
PITCH ANGLE OF THE VEHICLE > A THRESHOLD ANGLE?
NO
YES
1401
DETERMINE A FIRST PROPOSED REAR WHEEL STEERING ANGLE THAT IS THE PRODUCT OF A GAIN VALUE AND A FRONT WHEEL STEERING ANGLE
1402
DETERMINE A PROPOSED REAR WHEEL STEERING ANGLE PROPORTIONAL TO A STEERING ANGLE REQUEST AND CAUSE A FRONT WHEEL STEERING ANGLE TO BE SMALLER THAN THE REAR WHEEL STEERING ANGLE
1403
PROVIDE AN OUTPUT SIGNAL CONFIGURED TO CONTROL REAR WHEEL STEERING IN DEPENDENCE ON THE PROPOSED REAR WHEEL STEERING ANGLE
1404
1400

Fig. 11

Application No. GB1808998.7 RTM Date :3 December 2018

The following terms are registered trade marks and should be read as such wherever they occur in this document:

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AN APPARATUS AND A METHOD FOR CONTROLLING STEERING OF REAR WHEELS OF A VEHICLE

TECHNICAL FIELD

The present disclosure relates to an apparatus and a method for controlling steering. In particular, but not exclusively it relates to an apparatus and a method for controlling steering in a road vehicle, such as a car.

Aspects of the invention relate to an apparatus, a system, a vehicle, a method, a computer program and a non-transitory computer-readable storage medium having instructions stored therein.

BACKGROUND

When reversing or sliding backwards down a steep slope that has a deformable surface, or a surface providing very little grip, it is important to keep the vehicle on a straight path to prevent the vehicle turning and coming off-path or even rolling over. The stability of the vehicle, when reversing in this way, is a function of the gradient angle, such that the vehicle becomes less stable as the gradient angle increases.

It is known for some road vehicles to have four steerable wheels, which include rear wheels that are steered out of phase with the front wheels at low speeds, in order to make the vehicle more agile. However, such steering of the rear wheels makes it even more difficult to keep to a desired path while reversing or sliding backwards down a slope.

It is an aim of the present invention to address disadvantages of the prior art.

SUMMARY OF THE INVENTION

Aspects and embodiments of the invention provide an apparatus, a system, a vehicle, a method, a computer program and a non-transitory computer-readable storage medium as claimed in the appended claims.

According to an aspect of the invention there is provided an apparatus for controlling steering of rear wheels of a vehicle, the apparatus comprising a control means configured to: determine a rearwards movement condition of a vehicle; determine a pitch angle of the vehicle; determine a proposed rear wheel steering angle in dependence on a requested steering angle, the pitch angle of the vehicle and rearwards movement condition of the vehicle; and provide an output signal configured to control rear wheel steering in dependence on the proposed rear wheel steering angle.

This provides the advantage that when the vehicle is moving backwards down a slope the rear wheels may be steered in a manner that enables the vehicle to be more easily kept on a desired path. In instances where the slope is very steep, this may allow the vehicle to be more easily kept on a path down the slope that prevents the vehicle from rolling over.

In some embodiments the control means is configured to: determine a proposed rear wheel steering angle that is out of phase with a front wheel steering angle, in dependence on the pitch angle being less than a first threshold pitch angle; and determine a proposed rear wheel steering angle that is not out of phase with the front wheel steering angle, in dependence on the pitch angle being greater than the first threshold pitch angle. This provides the advantage that the vehicle is provided with increased maneuverability on less steep slopes but is easier to control when reversing down steeper slopes.

In some embodiments the control means is configured to: receive a signal indicative of a selected mode selected from at least a first mode and a second mode; and when the pitch angle is greater than the first threshold pitch angle, determine a proposed rear wheel steering angle that is out of phase with the front wheel steering angle in dependence on the first mode being selected, and determine a proposed rear wheel steering angle that is not out of phase with the front wheel steering angle in dependence on the second mode being selected. This provides the advantage that when the vehicle is on a terrain such as a tarmac road, in which it is easier to control the vehicle, the vehicle may continue to be provided with increased maneuverability but on other terrains such as a sand dune, or grass, gravel, snow, or mud, the rear wheels may be steered to make reversing down steeper slopes easier to control.

In some embodiments the control means is configured to determine a proposed rear wheel steering angle of zero degrees in dependence on the second mode being selected.

In some embodiments the control means is configured to receive the signal indicative of a selected mode from a terrain estimation system configured to produce the signal in dependence on detected characteristics of the ground on which the vehicle is travelling. This provides the advantage that the steering of the rear wheels is automatically altered in dependence of the terrain on which the vehicle is travelling.

In some embodiments the first mode is selectable in dependence on a determination that friction between the wheels of the vehicle and the ground in contact with the wheels is above a first friction threshold and the second mode is selectable in dependence on a determination that said friction is below the first friction threshold. This provides the advantage that when the vehicle is on a terrain such as a tarmac road, which provides a high level of grip, the vehicle may continue to be provided with increased maneuverability, while on other terrains that provide less grip, the rear wheels may be steered in a manner to make reversing down slopes easier to control.

In some embodiments the second mode is selectable in dependence on a determination that the ground in contact with the wheels is deformable by the wheels of the vehicle. This provides the advantage that steering of the rear wheels may be optimized to make reversing down slopes formed of material such as sand easier to control.

In some embodiments the apparatus is configured to receive the signal indicative of a selected mode from a user input device.

In some embodiments at least one performance characteristic of the vehicle is determined in dependence on the selected mode, the at least one performance characteristic comprising at least one of the group consisting of: accelerator pedal map; transmission map; stability control settings.

In some embodiments the proposed rear wheel steering angle is the product of the front wheel steering angle and a gain value, and the control means is configured to: determine a first proposed rear wheel steering angle with a first gain value in dependence on the pitch angle being below the first threshold pitch angle; and determine a second proposed rear wheel steering angle with a second gain value, of smaller magnitude than the first gain value, in dependence on the pitch angle being greater than a second threshold pitch angle. The second gain value may be positive or negative, and it may also be the same as the first gain value.

In some embodiments the control means is configured to determine the proposed rear wheel steering angle to be zero in dependence on determining that the pitch angle is greater than the second threshold pitch angle.

In some embodiments, in dependence on determining a rearwards movement condition and a pitch angle greater than a third threshold pitch angle, determine a proposed rear wheel steering angle that is proportional to the steering input, and determine a proposed front wheel steering angle that is proportional to the steering input and smaller than the rear wheel steering angle.

In some embodiments, in dependence on determining a rearwards movement condition and a pitch angle greater than a third threshold pitch angle, cause locking of the front steering and determine a proposed rear wheel steering angle proportional to the steering input.

In some embodiments the control means is configured to determine the rearwards movement condition in dependence on receiving a signal indicative of rearwards movement of the vehicle and/or receiving a signal indicative of a reverse gear of the vehicle being selected. This provides the advantage that the vehicle may be made easier to steer backwards down a slope when the reversing is intentional, as indicated by the reverse gear selection, and also when the reversing is caused by a failed climb, for example up a steep slope that has a low friction and/or deformable surface.

In some embodiments the control means is configured to determine a current condition of the vehicle as one of a plurality of predefined conditions and determine a proposed rear wheel steering angle that depends on the current condition; and the predefined conditions comprise at least one of: a low traction condition; oriented with a roll angle above a threshold roll angle.

In some embodiments the control means is configured to determine that the vehicle is not in the low traction condition when the pitch angle exceeds a fourth threshold pitch angle. This provides the advantage that if the vehicle comes to a halt due to a failed climb, for example up a steep slope that has a low friction and/or deformable surface, the control means controls the steering of the rear wheels to be optimized for reversing backwards down the slope, rather than incorrectly determining that the vehicle is stuck.

In some embodiments the control means comprises an electronic memory device and having instructions stored therein; and an electronic processor electrically coupled to the electronic memory device and configured to access the electronic memory device and execute the instructions.

According to another aspect of the invention there is provided a system comprising the apparatus of any one of the previous paragraphs and at least one actuator for controlling a steering angle of the rear wheels of the vehicle in response to the output signal.

According to yet another aspect of the invention there is provided a vehicle comprising the apparatus of any one of the previous paragraphs or the system of the previous paragraph.

According to a further aspect of the invention there is provided a method for controlling steering of rear wheels of a vehicle, the method comprising: determining a rearwards movement condition of a vehicle; determining a pitch angle of the vehicle; determining a proposed rear wheel steering angle in dependence on a requested steering angle, the pitch angle of the vehicle and the rearwards movement condition of the vehicle; and controlling rear wheel steering in dependence on the proposed rear wheel steering angle.

This provides the advantage that when the vehicle is moving backwards down a slope the rear wheels are steered in a manner that enables the vehicle to be more easily kept on a desired path. In instances where the slope is very steep, this may allow the vehicle to be more easily kept on a path down the slope that prevents the vehicle from rolling over.

In some embodiments the method comprises: determining a proposed rear wheel steering angle that is out of phase with a front wheel steering angle, in dependence on the pitch angle being less than a first threshold pitch angle; and determining a proposed rear wheel steering angle that is not out of phase with the front wheel steering angle, in dependence on the pitch angle being greater than the first threshold pitch angle. This provides the advantage that the vehicle is more easily maneuvered on less steep slopes but is easier to control when reversing down steeper slopes.

In some embodiments the method comprises: receiving a signal indicative of a selected mode selected from at least a first mode and a second mode; and when the pitch angle is greater than the first threshold pitch angle, determining a proposed rear wheel steering angle that is not out of phase with the front wheel steering angle in dependence on the second mode being selected, and determining a proposed rear wheel steering angle that is out of phase with the front wheel steering angle in dependence on the first mode being selected. This provides the advantage that when the vehicle is on a terrain such as a tarmac road, in which it is easier to control the vehicle, the vehicle may continue to be provided with increased maneuverability but on other terrains such as a sand dune, or grass, gravel, snow, or mud, the rear wheels may be steered to make reversing down steeper slopes easier to control.

In some embodiments the method comprises receiving the signal indicative of a selected mode from a terrain estimation system configured to produce the signal in dependence on detected characteristics of the ground on which the vehicle is travelling. This provides the advantage that the steering of the rear wheels is automatically altered in dependence of the terrain on which the vehicle is travelling.

In some embodiments the first mode is selected in dependence on a determination that friction between the wheels of the vehicle and the ground in contact with the wheels is above a first friction threshold and the second mode is selected in dependence on a determination that said friction is below the first friction threshold. This provides the advantage that when the vehicle is on a terrain such as a tarmac road, which provides a high level of grip, the vehicle may continue to be provided with increased maneuverability, while on other terrains that provide less grip, the rear wheels may be steered in a manner to make reversing down slopes easier to control.

In some embodiments the second mode is selected in dependence on a determination that the ground in contact with the wheels is deformable by the wheels of the vehicle. This provides the advantage that steering of the rear wheels may be optimized to make reversing down slopes formed of material such as sand easier to control.

In some embodiments the signal indicative of a selected mode is produced in dependence on a user input at a user input device.

In some embodiments the proposed rear wheel steering angle is the product of the front wheel steering angle and a gain value, and the method comprises: determining a first proposed rear wheel steering angle with a first gain value in dependence on the pitch angle being below a threshold pitch angle; and determining a second proposed rear wheel steering angle with a second gain value, smaller than the first gain value, in dependence on the pitch angle being greater than a second threshold pitch angle.

In some embodiments the method comprises determining the proposed rear wheel steering angle to be zero in dependence on determining that the pitch angle is greater than the second threshold pitch angle.

In some embodiments the method comprises determining a current state of the vehicle as one of a plurality of predefined conditions, and determining a proposed rear wheel steering angle that depends on the current condition; and the predefined conditions comprise at least one of: a low traction condition; oriented with a roll angle above a threshold roll angle.

According to a further aspect of the invention there is provided a computer program which when executed by a processor causes the processor to perform the method according to any one of the previous paragraphs.

Within the scope of this application it is expressly intended that the various aspects, embodiments, examples and alternatives set out in the preceding paragraphs, and/or in the following description and drawings, and in particular the individual features thereof, may be taken independently or in any combination that falls within the scope of the appended claims. That is, all embodiments and/or features of any embodiment can be combined in any way and/or combination that falls within the scope of the appended claims, unless such features are incompatible.

BRIEF DESCRIPTION OF THE DRAWINGS

One or more embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Fig. 1 shows a top view of a vehicle embodying the present invention;

Fig. 2 shows a top view of another vehicle embodying the present invention;

Fig. 3 shows a block diagram illustrating a system enabling steering of the vehicles of Figs. 1 and 2;

Fig. 4 shows a block diagram illustrating the functions performed by the control means illustrated in Fig. 3;

Fig. 5 shows a plan view of a vehicle travelling at a relatively high speed;

Fig. 6 shows a plan view of a vehicle travelling at a relatively low speed;

Fig. 7 shows a plan view of the vehicle travelling at a relatively low speed backwards down a sloping ground surface;

Fig. 8 shows a diagram illustrating the operation of the steering angle determination means in response to a determination that the vehicle is in its REVERSE DOWN condition;

Fig. 9 shows a flowchart illustrating a method embodying the present invention and performable by the control means to control steering of rear wheels of the vehicle when reversing down a slope;

Fig. 10 shows a flowchart illustrating a method, which provides an example of the method illustrated in Fig. 9; and

Fig. 11 shows a flowchart illustrating a method, which provides an alternative example of the method illustrated in Fig. 9.

DETAILED DESCRIPTION

A vehicle 100 embodying the present invention is shown in a top view in Fig. 1. The vehicle 100 is a car that is configured for use both on roads and off-road on various types of terrain. In the present embodiment, the vehicle 100 is a four wheel drive vehicle, but it will be appreciated that many of the features of the vehicle 100 described below are also applicable to rear wheeled drive vehicles.

Fig. 1 also shows, somewhat schematically, a system 101 configured to enable steering of the vehicle 100. The system 101 comprises an actuator 102 configured to cause steering of rear road wheels 103 of the vehicle 100, and also includes an apparatus 104 comprising a control means 105 for controlling the operation of the actuator 102.

In the present embodiment, front road wheels 106 of the vehicle 100 are steered by means of a mechanism 107 comprising a steering wheel 108, which is connected to a pinion 109 via a steering column 110. The pinion 109 engages a rack 111 which is connected to steering knuckles 112 by tie rods 113.

The rear wheels 103 are steerable by a mechanism 114 which is operated by the actuator 102. In the present embodiment the actuator 102 is configured to drive a second pinion 115 associated with a second rack 116 which provides forces to steering knuckles 117 of the rear wheels 103 via tie rods 118.

A steering input sensor 119 is configured to sense the orientation of the steering wheel 108 and provide signals to the control means 105 indicative of the orientation of the steering wheel 108 and therefore also indicative of the orientation of the front road wheels 106. The control means 105 is configured to provide output signals to the actuator 102 to cause steering of the rear wheels 103 in dependence of the signals received from the steering input sensor 119. However, the output signals provided to the actuator 102 are also dependent on other signals received by the control means 105, as will be described in detail below.

An alternative vehicle 100 embodying the present invention is shown in Fig. 2, in which a system 101 enables “steer-by-wire” of all wheels 103, 106 of the vehicle 100. The vehicle 100 of Fig. 2 has many features in common with that of Fig. 1, which have been provided with the same reference signs. Thus, like the vehicle 100 of Fig. 1, the vehicle 100 of Fig. 2 comprises a system 101 comprising pinion 109 and a rack 112 configured to operate steering knuckles 112 via tie rods 113, in order to steer the front wheels 106. A first actuator 102 is configured to drive a second pinion 115 associated with a second rack 116 which provides forces to steering knuckles 117 of the rear wheels 103 via tie rods 118.

However, in the embodiment of Fig. 2, the pinion 109 for driving the front wheels 106 is driven by a second actuator 202. The steering wheel 108 is mounted on a rotatable shaft 201 but it is not mechanically connected to the pinion 109. Instead, as well as providing signals to the actuator 102 for causing steering of the rear wheels 103, the control means 105 is also configured to provide signals to the second actuator 202 to cause steering of the front wheels 106 in dependence on signals it receives from the steering input sensor 119 located on the shaft 201 of the steering wheel 108.

In an alternative embodiment, the vehicle 100 has front wheels that are steer-by-wire, like those of Fig. 2, but the rear wheels 103 are not steerable.

The system 101 of Fig. 1, and that of Fig. 2, is illustrated by the block diagram shown in Fig. 3. The control means 105 comprises an electronic processor 301 and an electronic memory device 302 which stores instructions 303 performable by the processor 301 to cause the processor 301 to perform the method described below and output signals to the first steering actuator 102 to cause steering of the rear wheels 103. In the case of the vehicle 100 of Fig. 2, the processor 301 also provides signals to the second steering actuator 202 for steering the front wheels 106. Although only one processor and memory device are illustrated in Fig. 3, it will be understood that the control means 105 may comprise several processors 301 and/or several electronic memory devices 302, so that the processing as described below may be distributed over several processors.

As well as receiving signals from the steering input sensor 119, the control means 105 receives signals from wheel speed sensing means 304 indicative of a speed of rotation of each road wheel 103, 106. The wheel speed sensing means 304 may comprise wheel speed sensors, each of which is arranged to measure a speed of rotation of a respective one of the wheels 103, 106 and to provide a value for the speed of rotation directly to the control means 105. Alternatively, the wheel speed sensors may form a part of another system such as an antilock braking system (not shown) comprising a control unit configured to receive the signals from the wheel speed sensors and provide wheel speed values to the control means 105.

The control means 105 also receives signals from an inertial measurement unit (IMU) 305, which in the present embodiment comprises a six degrees of freedom IMU. The IMU 305 comprises accelerometers configured to measure longitudinal acceleration (a_x), lateral acceleration (a_y) and vertical acceleration (a_z) of the vehicle 100, and gyroscopes configured to measure a rate of roll (ω_x), a rate of pitch (ω_y) and a rate of yaw (ω_z) of the vehicle 100. The

IMU 305 is configured to provide indications of the measured accelerations (a_x, a_y, a_z) and angular velocities (ω_x, ω_y, ω_z) to the control means 105.

In the present embodiment, the vehicle 100 comprises several electronic control units for controlling subsystems of the vehicle 100. For example, the vehicle 100 comprises: an engine control unit (ECU) 307 for controlling operation of an engine (not shown) of the vehicle 100; a transmission control unit (TCU) 308 for controlling gear selection; and a suspension control unit (SCU) 309 for controlling properties of a suspension subsystem (not shown). Each of the subsystems is capable of working in several different modes, and the vehicle 100 comprises a vehicle control system 310 configured to control the mode in which the subsystems operate. For example, the engine control unit 307 may be controlled by the vehicle control system 310 to operate using an accelerator pedal map selected from several different maps; the transmission control unit 308 may be controlled to operate using a transmission map selected from several different maps; and the suspension control unit 309 may be controlled to operate using a set of stability control settings selected from several different sets.

Depending upon a user's style of driving or a type of terrain on which the vehicle 100 is travelling, one particular accelerator pedal map may be more appropriate than others, and similarly one particular transmission map and one particular set of stability control settings may be most appropriate. To enable a user to select the most appropriate settings for a chosen style of driving or a particular terrain, the vehicle 100 also comprises a user input device (UID) 311 configured to enable a user to indicate to the vehicle control system 310 a selected driving mode. For example, the user may select a standard mode (or normal mode) when driving on tarmac roads and the vehicle control system 310 controls the ECU 307, the TCU 308 and the SCU 309 to operate in a mode suitable for the tarmac road surface. Alternatively the user may select another mode, such as a grass, gravel and snow mode for driving over a terrain that provides a low coefficient of friction, or a sand mode for driving on a deformable surface such as sand, which provides a very low coefficient of friction, or a rock crawl mode for driving on rough surfaces with high friction. In response to such a user indication, the vehicle control system 310 controls the ECU 307, the TCU 308 and the SCU 309 to operate in a mode suitable for the indicated type of terrain. The mode selected by the use of the user input device 311 is also provided to the control means 105, and may be used to determine signals provided to the first steering actuator 102 and/or the second steering actuator 202.

The user input device 311 may comprise a switch or switches, a touch screen device, or other electrical or electronic device suitable for enabling a user to provide an indication of a mode they wish to select.

The vehicle control system 310 may comprise a terrain estimation system (TES) 306. Such a system is known and described in the applicant's UK patent GB2492655B and US patent application published as US2014350789A1. The terrain estimation system 310 is configured to select a driving mode that is the most appropriate mode for the subsystems 307, 308, 309 based on measurements indicative of the terrain on which the vehicle 100 is travelling, to enable the vehicle control system 310 to automatically control the subsystems 307, 308, 309 to operate in the selected mode.

The TES 306 receives signals from terrain sensing means 312 comprising various different sensors and devices for providing information indicating the type of terrain on which the vehicle 100 is travelling. The terrain sensing means 312 may include the aforementioned IMU 305, wheel speed sensing means 304, steering input sensor 119, as well as other sensors (not shown), such as an ambient temperature sensor, an atmospheric pressure sensor, an engine torque sensor, a brake pedal position sensor, an acceleration pedal position sensor, ride height sensors, etc. Various outputs from the terrain sensing means 312 are used by the terrain estimation system 310 to derive a number of terrain indicators. For example, a vehicle speed is derived from the wheel speed sensors, wheel acceleration is derived from the wheel speed sensors, the longitudinal force on the wheels is derived from the IMU 305, and the torque at which wheel slip occurs (if wheel slip occurs) is derived from the motion sensors of the IMU 305 to detect yaw, pitch and roll. The terrain indicators are then processed to determine a probability that each of the different driving modes is appropriate, and thereby determine which of the modes is most appropriate for the operation of the subsystems. In its automatic mode, the terrain estimation system 310 continually determines for each mode the probability that it is appropriate and in dependence on another mode having a consistently higher probability than the currently selected control mode, the vehicle control system 310 commands the subsystems to operate in accordance with that other mode.

The mode determined automatically by the terrain estimation system 306, or selected by the use of the user input device 311, is also provided to the control means 105, and may be used to determine signals provided to the first steering actuator 102 and/or the second steering actuator 202.

A block diagram illustrating the functions performed by the control means 105 is shown in Fig. 4. The control means 105 may comprise a vehicle state estimation means 401 which receives signals from the IMU 305 comprising measurements of at least the longitudinal acceleration (a_x), the lateral acceleration (a_y), the rate of roll (ω_x), the rate of pitch (ω_y) and the rate of yaw (ω_z) of the vehicle 100. The vehicle state estimation means 401 also receives an indication of the currently selected gear, for example from the TCU 308 via a CAN (RTM) (Controller Area Network) bus. The vehicle state estimation means 401 also receives signals from the steering input sensor 119 indicative of a requested steering angle and the wheel speed sensing means 304 comprising measurements of the angular velocity of the wheels 103, 106.

The vehicle state estimation means 401 processes the received data (i.e. the selected gear, the requested steering angle and measurements from the IMU 305 and wheel speed sensing means 304) to determine and repeatedly update a plurality of state values that provide an estimate of a current state of the vehicle 100. In the present embodiment, the vehicle state estimation means 401 comprises a Kalman filter into which the received data is input and which generates at least some of the state values. The state values comprise estimates of the roll angle (θ_x), the pitch angle (θ_y), the longitudinal velocity (V_x), longitudinal acceleration (a_x) and centripetal acceleration of the vehicle over the ground, as well as a yaw rate target, a yaw rate measurement, a steering angle and a vehicle direction indication, which indicates if a reverse gear is currently selected.

The yaw rate target is an estimate of the current rate of yaw of the vehicle 100 and it is calculated from the steering angle and the estimate of the longitudinal velocity (V_x) of the vehicle 100 over the ground using a simple mathematical model commonly referred to as a bicycle model. The yaw rate measurement is the rate of yaw measured by the IMU 305.

The control means 105 comprises a state detection means 402 which receives the state values provided by the vehicle state estimation means 401, as well as an indication of a currently selected driving mode and an indication of a powertrain torque request, such as from a throttle position sensor. The state detection means 402 is configured to analyse the state values, selected driving mode and powertrain torque request to determine whether or not the vehicle 100 is currently in a predefined special condition or alternatively in a standard condition. In the present embodiment, the vehicle state estimation means 401 is configured to determine whether the vehicle 100 is in any one of three special conditions, labelled REVERSE DOWN, LOW TRACTION and BANK in Fig. 4, or in its STANDARD condition.

An indication of whether the vehicle 100 is determined to be in one of the predefined special conditions or in the STANDARD condition is provided to a steering angle determination means 403. One or more of the state values, such as longitudinal velocity (V_x) or roll angle (θ_x), is also received by the steering angle determination means 403 along with the requested steering angle received from the steering input sensor 119. The steering angle determination means 403 is configured to determine a proposed rear wheel steering angle in dependence on at least the requested steering angle received from the steering input sensor 119, the state of the vehicle 100 determined by the state detection means 402 and received state values. The control means 105 is configured to provide an output signal to the first steering actuator 102 to control rear wheel steering in dependence on the proposed rear wheel steering angle.

In an embodiment, such as that of Fig. 2, in which the vehicle 100 is steer-by-wire, the steering angle determination means 403 may be configured to additionally determine a proposed front wheel steering angle in dependence on at least the requested steering angle, the state of the vehicle 100 determined by the state detection means 402 and received state values. The control means 105 is then configured to provide an output signal to the second steering actuator 202 to control front wheel steering in dependence on the proposed front wheel steering angle.

Further details of how the REVERSE condition is detected and how the proposed steering angle is determined will be described below. However, the STANDARD condition, which is established when none of the defined special conditions are detected, will firstly be described with reference to Figs. 5 and 6.

Figs. 5 and 6 show plan views of the vehicle 100 travelling at a relatively high speed and a relatively low speed respectively. In both Figs. 5 and 6 the front wheels 106 are turned approximately 15 degrees relative to the longitudinal axis 501 of the vehicle 100 to cause the vehicle 100 to turn leftwards. In Fig. 5, the current speed of the vehicle 100, as determined from the wheel speed sensing means 304, is above a threshold speed and consequently the rear wheels 103 have been steered in phase with the front wheels 106. That is, because the front wheels 106 have been turned to the left, the rear wheels 103 are also turned to the left. As is known, steering the rear wheels 103 in phase with the front wheels 106 provides the vehicle 100 with increased stability, which is advantageous at high speeds.

In Fig. 5, the rear wheels 103 have only been steered leftwards by about 1.5 degrees, i.e. a tenth of the angle turned by the front wheels 106. The proportion of the front wheel steering angle by which the rear wheels 103 have been steered is referred to herein as the gain value. Thus, in this example the rear wheel steering has a gain value of +0.1 (= 1.5/15).

In Fig. 6 the current speed of the vehicle 100 is below the threshold speed and consequently the rear wheels 103 have been steered out of phase with the front wheels 106. That is, because the front wheels 106 have been turned to the left, the rear wheels 103 have been turned to the right. Stability of the vehicle 100 is not an issue at low speeds and, as is known, steering the rear wheels 103 out of phase with the front wheels 106 provides the vehicle 100 with increased agility.

The rear wheels 103 have been steered rightwards by about 3 degrees, i.e. a fifth of the angle turned by the front wheels 106. Thus, in this example the rear wheel steering has a gain value of -0.2 (= -3 /15). i.e. the absolute value (0.2) of the gain value is higher than the gain value for speeds above the threshold speed, but the gain value is negative due to the rear wheels 103 being turned out of phase with the front wheels 106.

A special condition of the vehicle 100, labelled REVERSE DOWN in Fig. 4 will now be described with reference to Figs. 7 to 11. Fig. 7 shows a plan view of the vehicle 100 travelling at a relatively low speed backwards down a sloping ground surface 1001. Arrows 1002 indicate directions down along the ground surface 1001 and arrow 1003 represents the velocity of the vehicle 100, which is approximately parallel to the arrows 1002.

As discussed above with reference to Figs. 5 and 6, it is known for vehicles with four steerable wheels to steer the rear wheels out of phase with the front wheels at low speeds, i.e. from speeds of 0kmph up to a threshold speed. It is also known to steer the rear wheels out of phase with the front wheels when the vehicle 100 is reversing. However, as shown in Fig. 7, the vehicle 100 may be arranged, on some terrains such as sand, to steer the rear wheels 103 in phase with the front wheels when reversing down an incline. This prevents the front of the vehicle 100 swinging down the slope lower than desired when steering backwards down the slope. Therefore the stability of the vehicle 100 is increased in such a situation and the vehicle is easier to control. Also, in dependence on the steepness of the incline and/or the friction provided by its surface, and/or a selected driver mode, the vehicle 100 may be arranged not to steer the rear wheels at all.

Operation of the steering angle determination means 403 and the state detection means 402 when it determines that the vehicle 100 is in its REVERSE DOWN condition is illustrated in Fig. 8. The state detection means 402 receives: an indication of the pitch angle (θ_y) of the vehicle 100 from the vehicle state estimation means 401; an indication (from the currently selected gear) of the intended direction (backwards or forwards) of the vehicle 100; an indication of the longitudinal velocity (V_x) of the vehicle, or alternatively the sign (positive or negative) of the longitudinal velocity; the currently selected driving mode; and the requested steering angle.

The state detection means 402 determines that the vehicle 100 is in a rearwards movement condition if the longitudinal velocity is negative, indicating rearwards movement. The rearwards movement may be due to intentional reversing of the vehicle 100, or due to the vehicle 100 sliding backwards down a slope when it has failed to climb up it, for example, due to the slope having a very low friction surface or due to it being composed of loose particulate material such as sand. In the present embodiment, the state detection means 402 also determines that the vehicle 100 is in a rearwards movement condition, even if it is stationary, if the intended vehicle direction (indicated by reverse gear being selected) is backwards.

In dependence on the pitch angle (θ_y) being above a threshold pitch angle and a determination that the vehicle 100 is in a rearwards movement condition, the state detection means 402 determines the vehicle is in the REVERSE DOWN condition. In dependence on such a determination, the steering angle determination means 403 determines a proposed rear wheel steering angle in dependence on the requested steering angle.

In the present embodiment, the proposed steering angle is also determined in dependence on the currently selected driving mode. For example, in dependence on a first driving mode being selected, which may be a standard mode for driving on tarmac surfaced roads and the like, a proposed rear wheel steering angle is determined by multiplying a negative gain value (such as that selected for the STANDARD condition) and the requested steering angle. Consequently the rear wheels 103 are steered out of phase with the front wheels 106. This provides the vehicle 100 with good maneuverability, which may be advantageous, for example when parking.

Alternatively a second driving mode may be selected, which may be a mode for driving on low friction and/or rough surfaces, such as grass, gravel, snow, a muddy rutted surface, or a rocky rough surface. In dependence on such a second driving mode being selected, a proposed rear wheel steering angle may be determined using a gain value with a small magnitude compared to the gain value used for the first driving mode. In an example, the gain value used for the second driving mode is zero, and so the rear wheels 103 are caused to be held at zero degrees.

Alternatively a third driving mode may be selected, which may be a mode for driving on deformable material such as sand. As described with reference to Fig. 7, in dependence on such a third driving mode being selected, a proposed rear wheel steering angle may be determined as the product of the requested steering angle and a positive gain value, so that the rear wheels 103 are steered in phase with the front wheels 106.

In an alternative embodiment, in which all road wheels 103, 106 are steer-by-wire, like those of Fig. 2, in at least one driving mode, in dependence on determining a rearwards movement condition and determining that the pitch angle of the vehicle is greater than a threshold pitch angle, the control means 105 causes the vehicle 100 to steer backwards by steering the rear wheels 103 only. In this embodiment, the steering angle determination means 403 is configured to cause the front wheels 106 to be locked in position at zero degrees and to determine a proposed rear wheel steering angle proportional to the requested steering angle. In another alternative embodiment, in which all road wheels 103, 106 are steer-by-wire, as in Fig. 2, in at least one driving mode in dependence on determining a rearwards movement condition and determining that the pitch angle of the vehicle is greater than a threshold pitch angle, the control means 105 causes steering of the vehicle 100 to be primarily performed by the rear wheels 106. In such a scenario, the control means 105 may cause steering by all road wheels 103, 106 in proportion to the requested steering angle received from the steering input sensor 119 but the rear wheels 103 are steered through larger angles than the front wheels 106.

A flowchart illustrating a method 1200 embodying the present invention and performable by the control means 105, to control steering of rear wheels 103 of the vehicle 100 when reversing down a slope, is shown in Fig. 9. At block 1201 a rearwards movement condition of a vehicle 100 is determined. This may comprise receiving a signal indicating that a reverse gear of the vehicle 100 has been selected or reverse movement of the vehicle 100 has been detected.

At block 1202 the pitch angle of the vehicle 100 is determined. This may comprise receiving a signal indicative of the pitch angle from another processing means, or determining the pitch angle from signals received from sensing means such as a gyroscope device or an inertial measurement unit 305.

At block 1203 a proposed rear wheel steering angle is determined in dependence on a requested steering angle, the pitch angle and the rearwards movement condition of the vehicle 100. At block 1204 an output signal is provided, which is configured to control steering of the rear wheels 103 of the vehicle 100 in dependence on the proposed rear wheel steering angle. The output signal may be provided to an actuator 102 for controlling steering of the rear wheels of the vehicle 100, so that the actuator turns the rear wheels 103 to the proposed rear wheel steering angle.

A method 1300, which provides an example of the method 1200, is illustrated by the flowchart shown in Fig. 10. At block 1201 a rearwards movement condition of a vehicle 100 is determined, and at block 1301 a signal is received that is indicative of a driving mode selected from at least a first mode and a second mode. For example, the signal may be received from a user input device 311 in response to a user selection or from a terrain estimation system 310 as described above with reference to Fig. 3. At block 1302 it is determined whether the pitch angle of the vehicle 100 is greater than a threshold pitch angle. If it is not, at block 1305 a proposed rear wheel steering angle, which is out of phase with the front wheel steering angle, is determined in dependence on a requested steering angle. I.e., the proposed rear wheel steering angle is the product of the front wheel steering angle and a negative gain value.

Alternatively, if it is determined at block 1302 that the pitch angle of the vehicle 100 is greater than the threshold pitch angle, it is then determined at block 1303 whether a first mode is currently selected. For example, the first mode may be indicative of the vehicle being used on a terrain where stability of the vehicle 100 when reversing down an incline is not an issue. For example, the first mode may be indicative of the vehicle 100 being used on a tarmac road and/or indicative of friction between the road wheels 103, 106 of the vehicle 100 and the terrain being above a friction threshold.

In an embodiment, the threshold pitch angle used at block 1302 is a constant value of, for example, 10 degrees, but in other embodiments the threshold pitch angle is dependent on the currently selected driving mode.

If it is determined that the first mode is selected then the aforementioned process at block 1305 is performed. Alternatively, if it is determined at block 1303 that another mode is currently selected, for example suitable for use on a low friction surface or a deformable surface such as sand, a proposed rear wheel steering angle is determined at block 1304. The determination at block 1304 produces a proposed rear wheel steering angle that is not out of phase with the front wheel steering angle. As described above, the proposed steering angle may be calculated using a gain value of zero, or close to zero (i.e. below 0.1), for low friction surfaces, or a positive gain value for deformable surfaces such as sand.

Following the determination of the proposed steering angle at block 1304 or block 1305, an output signal is provided at block 1204 configured to control rear wheel steering in dependence on the proposed rear wheel steering angle.

An alternative method 1400, which provides a second example of the method 1200, is illustrated by the flowchart shown in Fig. 11. At block 1201 a rearwards movement condition of a vehicle 100 is determined, and at block 1401 it is determined whether the pitch angle of the vehicle is greater than a threshold pitch angle. If it is not, a first proposed rear wheel steering angle is determined at block 1402 that is the product of a gain value and a front wheel steering angle. Alternatively, if it is determined at block 1401 that the pitch angle of the vehicle is greater than the threshold pitch angle, a proposed rear wheel steering angle is determined that is proportional to the requested steering angle. In addition, the front wheels 106 of the vehicle 100 are caused to be steered through angles that are proportional to the requested steering angle but smaller than those of the rear wheels 103, so that the vehicle 100 is primarily steered by the rear wheels 103. In one embodiment, the front wheels 106 may be locked at zero degrees and the vehicle 106 is only steered by the rear wheels 103. At block 1404 an output signal is provided, for example to actuator 102, to control steering of the rear wheels in dependence on the proposed rear wheel steering angle. Thus, the front wheels are locked and steering is performed using the rear wheels only.

For purposes of this disclosure, it is to be understood that the control means/controller(s) described herein can each comprise a control unit or computational device having one or more electronic processors. A vehicle and/or a system thereof may comprise a single control unit or electronic controller or alternatively different functions of the controller(s) may be embodied in, or hosted in, different control units or controllers. A set of instructions could be provided which, when executed, cause said controller(s) or control unit(s) to implement the control techniques described herein (including the described method(s)). The set of instructions may be embedded in one or more electronic processors, or alternatively, the set of instructions could be provided as software to be executed by one or more electronic processor(s). For example, a first controller may be implemented in software run on one or more electronic processors, and one or more other controllers may also be implemented in software run on or more electronic processors, optionally the same one or more processors as the first controller. It will be appreciated, however, that other arrangements are also useful, and therefore, the present disclosure is not intended to be limited to any particular arrangement. In any event, the set of instructions described above may be embedded in a computer-readable storage medium (e.g., a non-transitory computer-readable storage medium) that may comprise any mechanism for storing information in a form readable by a machine or electronic processors/computational device, including, without limitation: a magnetic storage medium (e.g., floppy diskette); optical storage medium (e.g., CD-ROM); magneto optical storage medium; read only memory (ROM); random access memory (RAM); erasable programmable memory (e.g., EPROM or EEPROM); flash memory; or electrical or other types of medium for storing such information/instructions.

The blocks illustrated in the Figs. 9 to 11 may represent steps in a method and/or sections of code in the computer program 303. The illustration of a particular order to the blocks does not necessarily imply that there is a required or preferred order for the blocks and the order and arrangement of the block may be varied. Furthermore, it may be possible for some steps to be omitted.

Although embodiments of the present invention have been described in the preceding paragraphs with reference to various examples, it should be appreciated that modifications to the examples given can be made without departing from the scope of the invention as claimed. For example, in alternative embodiments, the control means 105 may be configured to control steering of rear wheels 103 of the vehicle 100 in the REVERSE condition, as described with reference to Figs. 7 to 11, but not in any, or only in selected ones, of the other conditions. It will also be understood that the control means 105 may be configured to detect other special conditions, in addition to those described, and to control rear wheel steering in a manner that is customized for those other special conditions.

Whilst endeavoring in the foregoing specification to draw attention to those features of the invention believed to be of particular importance it should be understood that the Applicant claims protection in respect of any patentable feature or combination of features hereinbefore referred to and/or shown in the drawings that falls within the scope of the appended claims whether or not particular emphasis has been placed thereon.

CLAIMS

1. An apparatus for controlling steering of rear wheels of a vehicle, the apparatus comprising a control means configured to:

determine a rearwards movement condition of a vehicle;

determine a pitch angle of the vehicle;

determine a proposed rear wheel steering angle in dependence on a requested steering angle, the pitch angle of the vehicle and rearwards movement condition of the vehicle; and

provide an output signal configured to control rear wheel steering in dependence on the proposed rear wheel steering angle.

2. An apparatus according to claim 1, wherein the control means is configured to: determine a proposed rear wheel steering angle that is out of phase with a front wheel steering angle, in dependence on the pitch angle being less than a first threshold pitch angle; and determine a proposed rear wheel steering angle that is not out of phase with the front wheel steering angle, in dependence on the pitch angle being greater than the first threshold pitch angle.

3. An apparatus according to claim 2, wherein the control means is configured to: receive a signal indicative of a selected mode selected from at least a first mode and a second mode; and when the pitch angle is greater than the first threshold pitch angle, determine a proposed rear wheel steering angle that is out of phase with the front wheel steering angle in dependence on the first mode being selected, and determine a proposed rear wheel steering angle that is not out of phase with the front wheel steering angle in dependence on the second mode being selected.

4. An apparatus according to claim 3, wherein the control means is configured to determine a proposed rear wheel steering angle of zero degrees in dependence on the second mode being selected.

5. An apparatus according to claim 3 or claim 4, wherein the control means is configured to receive the signal indicative of a selected mode from a terrain estimation system configured

to produce the signal in dependence on detected characteristics of the ground on which the vehicle is travelling.

6. An apparatus according to any one of claims 3 to 5, wherein the first mode is selectable in dependence on a determination that friction between the wheels of the vehicle and the ground in contact with the wheels is above a first friction threshold and the second mode is selectable in dependence on a determination that said friction is below the first friction threshold.

7. An apparatus according to any one of claims 3 to 6, wherein the second mode is selectable in dependence on a determination that the ground in contact with the wheels is deformable by the wheels of the vehicle.

8. An apparatus according to claim 3 or claim 4, wherein the apparatus is configured to receive the signal indicative of a selected mode from a user input device.

9. An apparatus according to any one of claims 3 to 8, wherein at least one performance characteristic of the vehicle is determined in dependence on the selected mode, the at least one performance characteristic comprising at least one of the group consisting of: accelerator pedal map; transmission map; stability control settings.

10. An apparatus according to any one of claims 1 to 9, wherein the proposed rear wheel steering angle is the product of the front wheel steering angle and a gain value, and the control means is configured to: determine a first proposed rear wheel steering angle with a first gain value in dependence on the pitch angle being below the first threshold pitch angle; and determine a second proposed rear wheel steering angle with a second gain value, of smaller magnitude than the first gain value, in dependence on the pitch angle being greater than a second threshold pitch angle.

11. An apparatus according to claim 10, wherein the control means is configured to determine the proposed rear wheel steering angle to be zero in dependence on determining that the pitch angle is greater than the second threshold pitch angle.

12. An apparatus according to claim 1, wherein, in dependence on determining a rearwards movement condition and a pitch angle greater than a third threshold pitch angle, determine a proposed rear wheel steering angle that is proportional to the steering input, and determine a proposed front wheel steering angle that is proportional to the steering input and smaller than the rear wheel steering angle.

13. An apparatus according to any one of claims 1 to 12, wherein the control means is configured to determine the rearwards movement condition in dependence on receiving a signal indicative of rearwards movement of the vehicle and/or receiving a signal indicative of a reverse gear of the vehicle being selected.

14. A system comprising the apparatus of any one of claims 1 to 13 and at least one actuator for controlling a steering angle of the rear wheels of the vehicle in response to the output signal.

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15. A vehicle comprising the apparatus of any one of claims 1 to 13 or the system of claim 14.

16. A method for controlling steering of rear wheels of a vehicle, the method comprising:

determining a rearwards movement condition of a vehicle;

determining a pitch angle of the vehicle;

determining a proposed rear wheel steering angle in dependence on a requested steering angle, the pitch angle of the vehicle and the rearwards movement condition of the vehicle; and

controlling rear wheel steering in dependence on the proposed rear wheel steering angle.

17. A method according to claim 16, wherein the method comprises: determining a proposed rear wheel steering angle that is out of phase with a front wheel steering angle, in dependence on the pitch angle being less than a first threshold pitch angle; and determining a proposed rear wheel steering angle that is not out of phase with the front wheel steering angle, in dependence on the pitch angle being greater than the first threshold pitch angle.

18. A method according to claim 17, wherein the method comprises: receiving a signal indicative of a selected mode selected from at least a first mode and a second mode; and when the pitch angle is greater than the first threshold pitch angle, determining a proposed rear wheel steering angle that is not out of phase with the front wheel steering angle in dependence on the second mode being selected, and determining a proposed rear wheel steering angle that is out of phase with the front wheel steering angle in dependence on the first mode being selected.

19. A method according to claim 18, wherein the method comprises receiving the signal indicative of a selected mode from a terrain estimation system configured to produce the signal in dependence on detected characteristics of the ground on which the vehicle is travelling.

20. A method according to claim 18 or claim 19, wherein the first mode is selected in dependence on a determination that friction between the wheels of the vehicle and the ground in contact with the wheels is above a first friction threshold and the second mode is selected in dependence on a determination that said friction is below the first friction threshold.

21. A method according to any one of claims 18 to 20, wherein the second mode is selected in dependence on a determination that the ground in contact with the wheels is deformable by the wheels of the vehicle.

22. A method according to any one of claims 16 to 21, wherein the proposed rear wheel steering angle is the product of the front wheel steering angle and a gain value, and the method comprises: determining a first proposed rear wheel steering angle with a first gain value in dependence on the pitch angle being below a threshold pitch angle; and determining a second proposed rear wheel steering angle with a second gain value, smaller than the first gain value, in dependence on the pitch angle being greater than a second threshold pitch angle.

23. A method according to any one of claims 16 to 22, wherein the method comprises determining the proposed rear wheel steering angle to be zero in dependence on determining that the pitch angle is greater than the second threshold pitch angle.

24. A method according to any one of claims 16 to 23, wherein: the method comprises determining a current state of the vehicle as one of a plurality of predefined conditions, and determining a proposed rear wheel steering angle that depends on the current condition; and the predefined conditions comprise at least one of: a low traction condition; oriented with a roll angle above a threshold roll angle.

25. A computer program which when executed by a processor causes the processor to perform the method according to any one of claims 16 to 24.