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(54) WORK MACHINE AND METHOD FOR CONTROLLING WORK MACHINE

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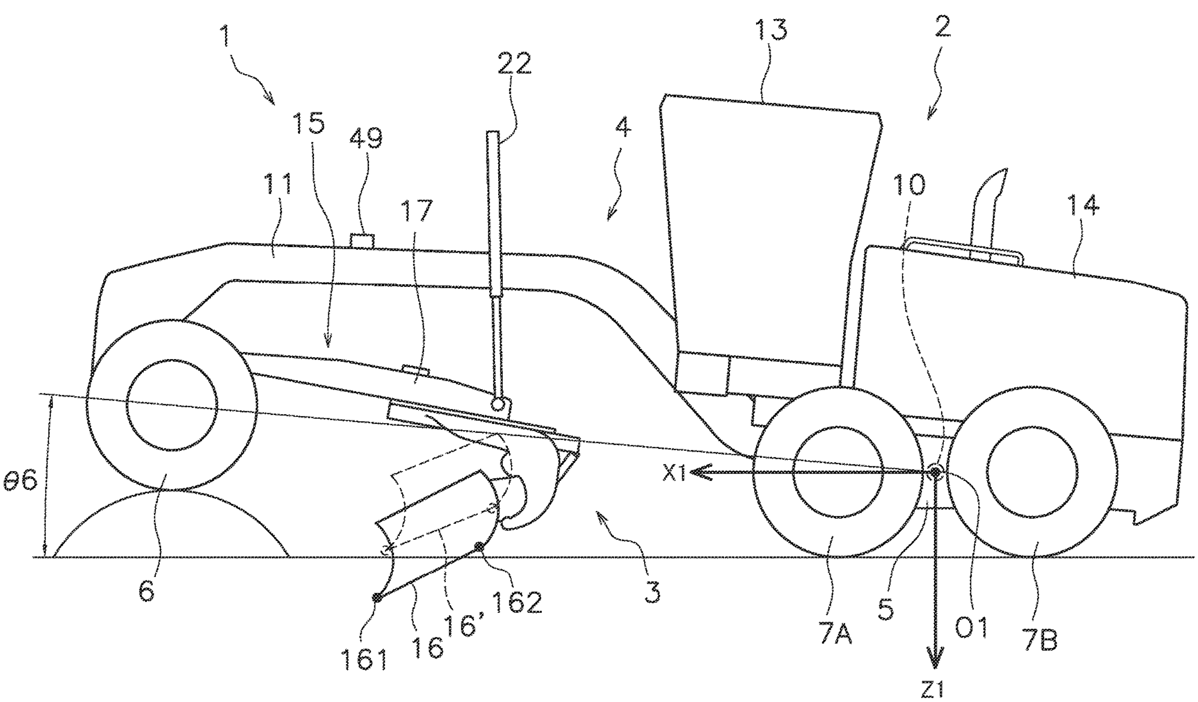
(57) **ABSTRACT**

A controller acquires vehicle body posture data. The controller acquires work implement posture data. The controller calculates a height of a work implement in a gravity direction from a reference point of a vehicle body based on the vehicle body posture data and the work implement posture data. The controller controls an actuator so that the height of the work implement in the gravity direction is maintained even when a posture of the vehicle body changes.



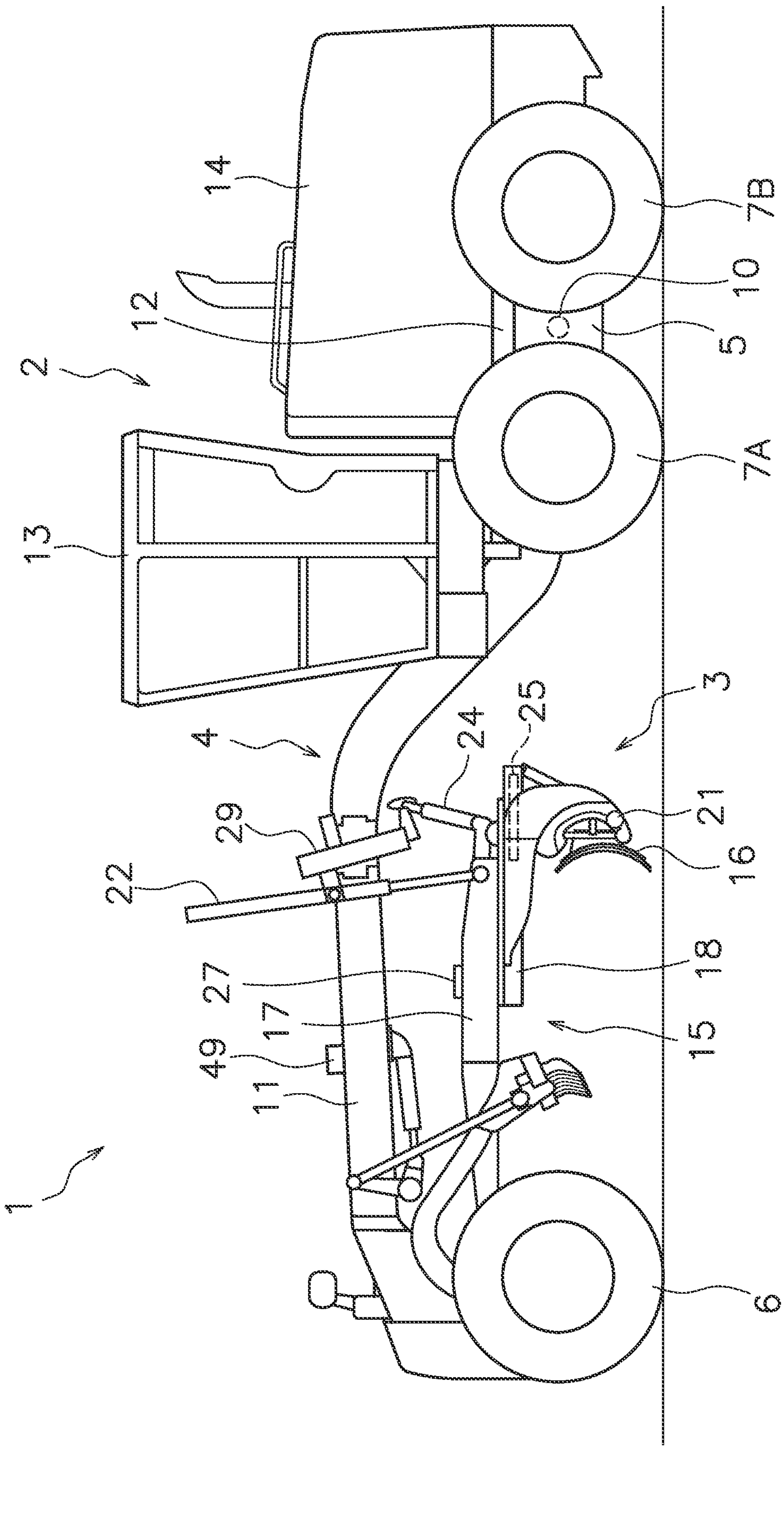


FIG. 1

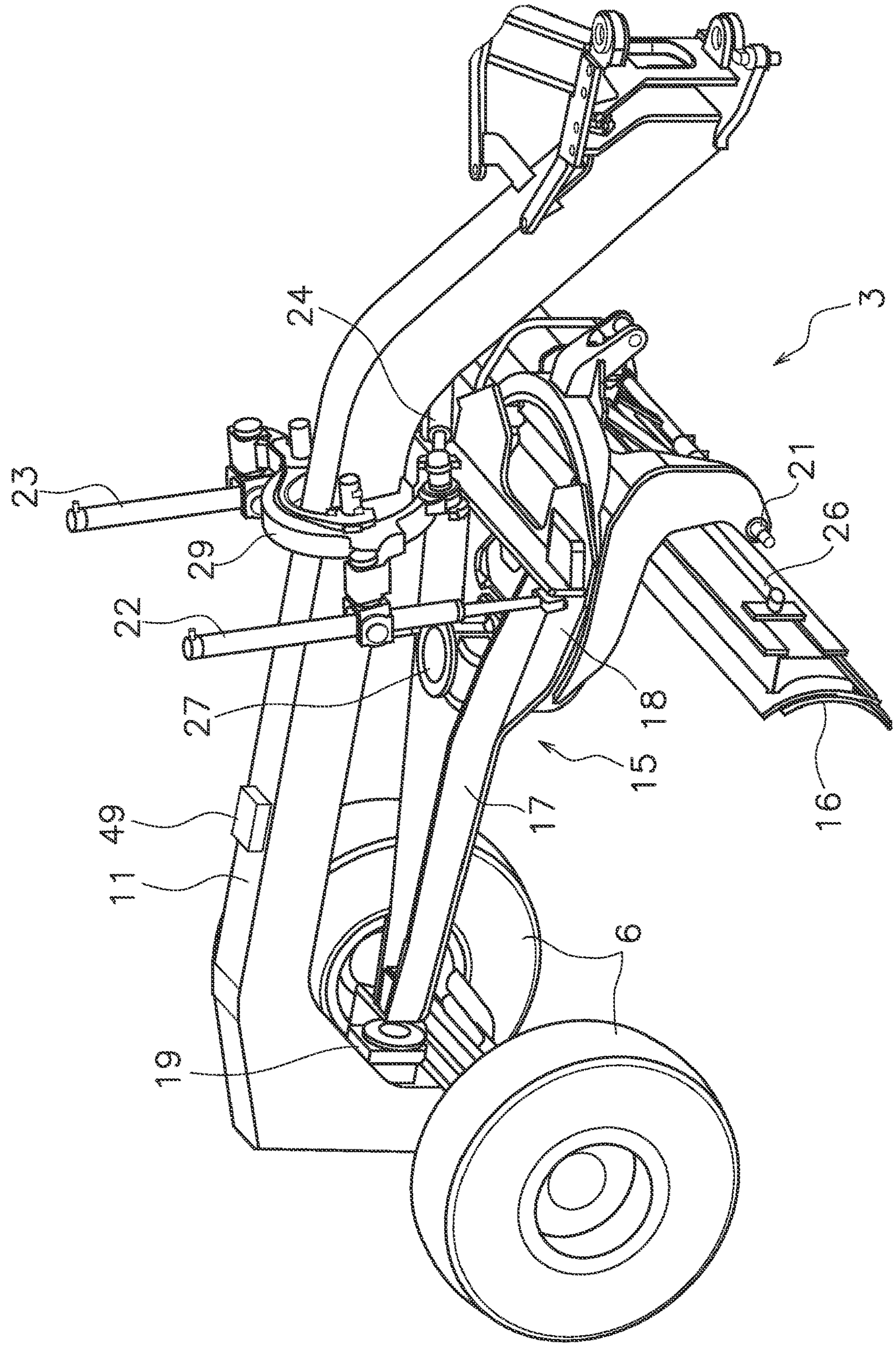


FIG. 2

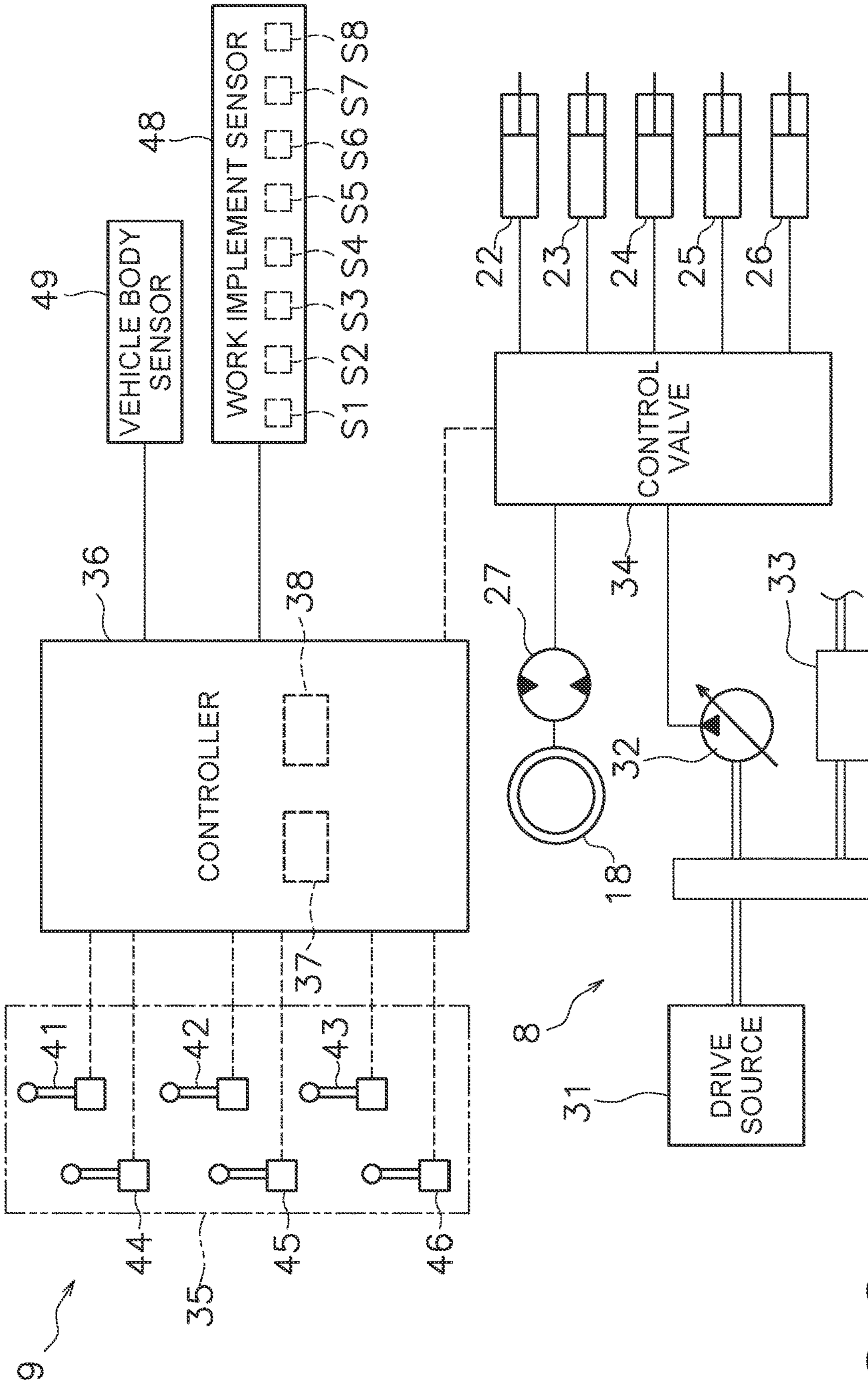

49
VEHICLE BODY SENSOR
48
WORK IMPLEMENT SENSOR
S1 S2 S3 S4 S5 S6 S7 S8
22
23
24
25
26
CONTROL VALVE
36
38
CONTROLLER
37
27
34
33
32
18
8
31
DRIVE SOURCE
41
42
43
44
45
46
35
9

FIG. 3

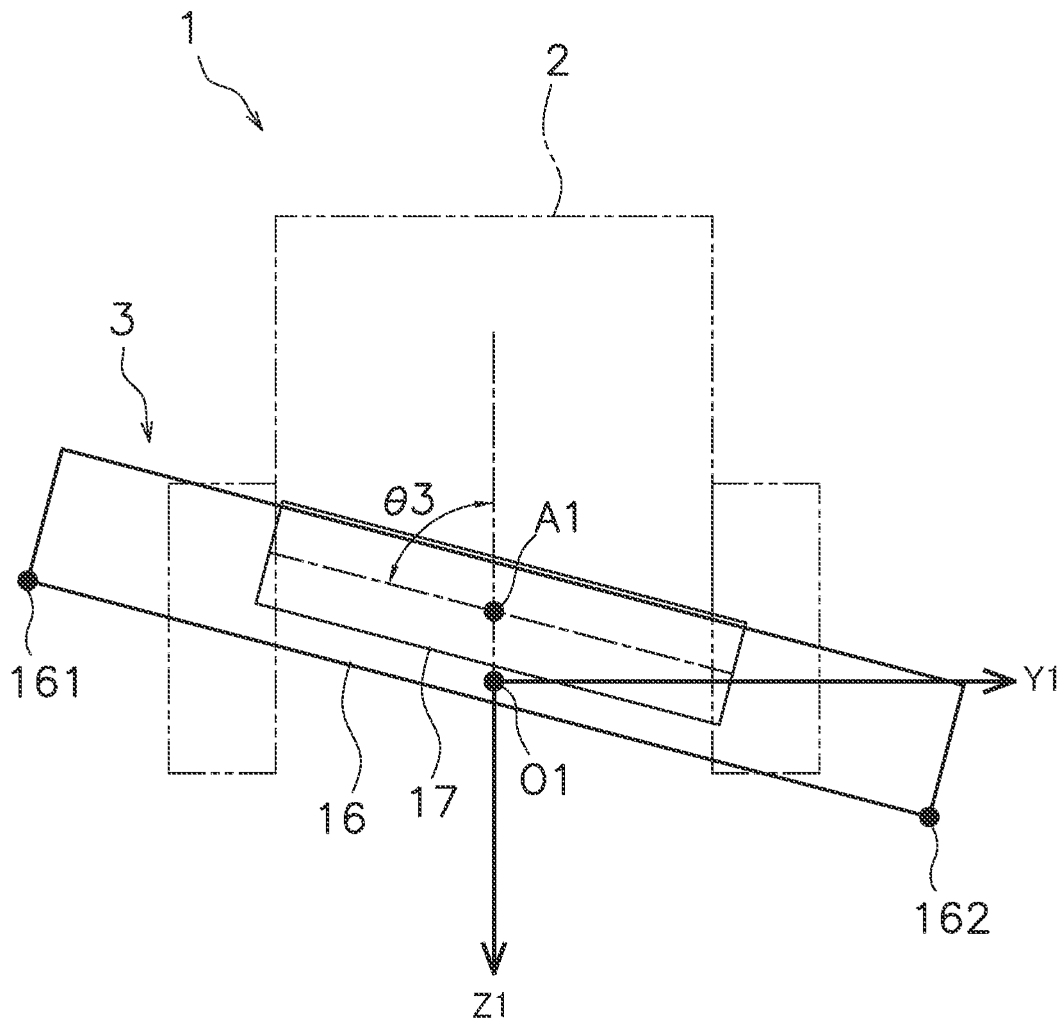


FIG. 4

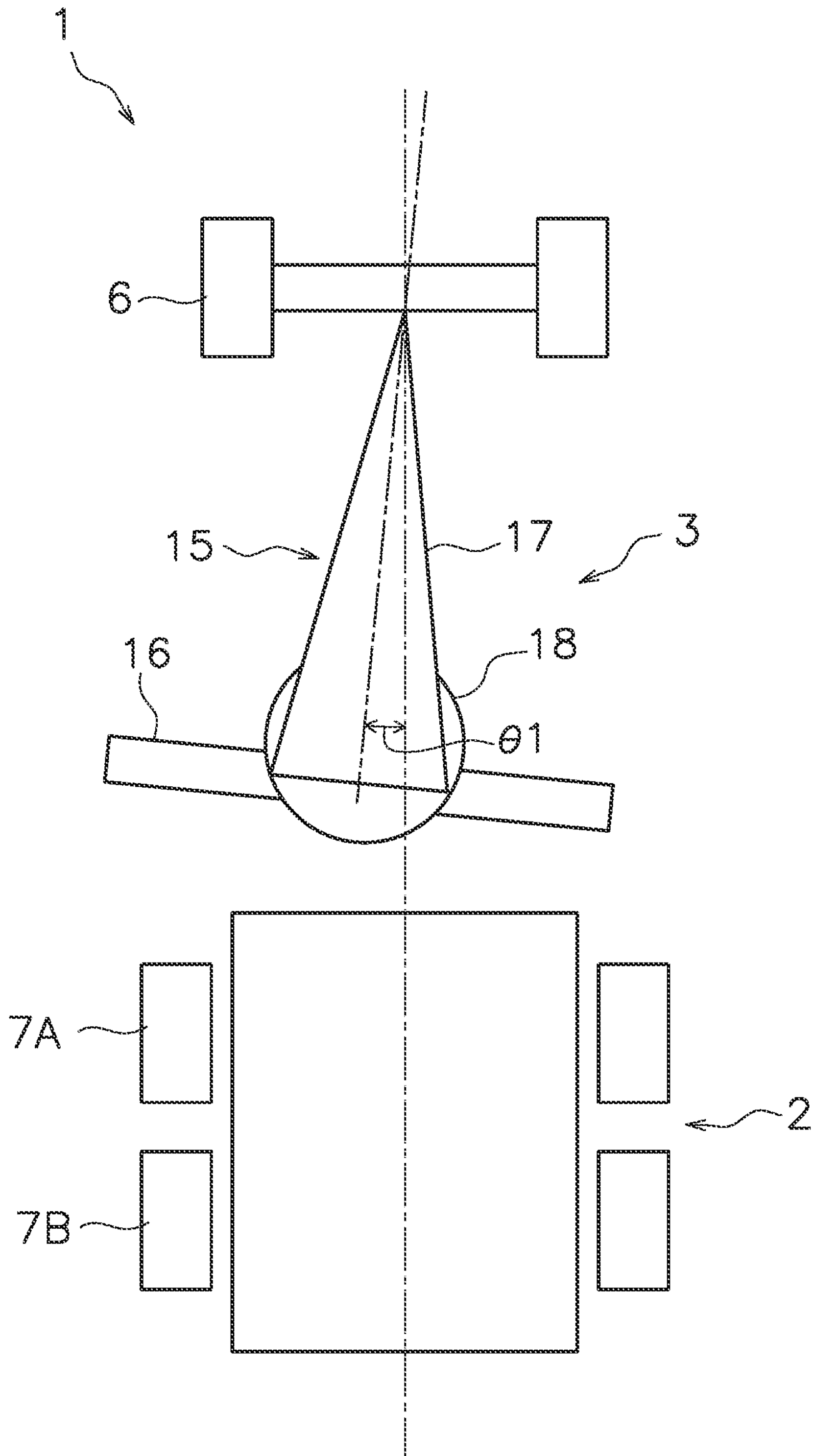


FIG. 5

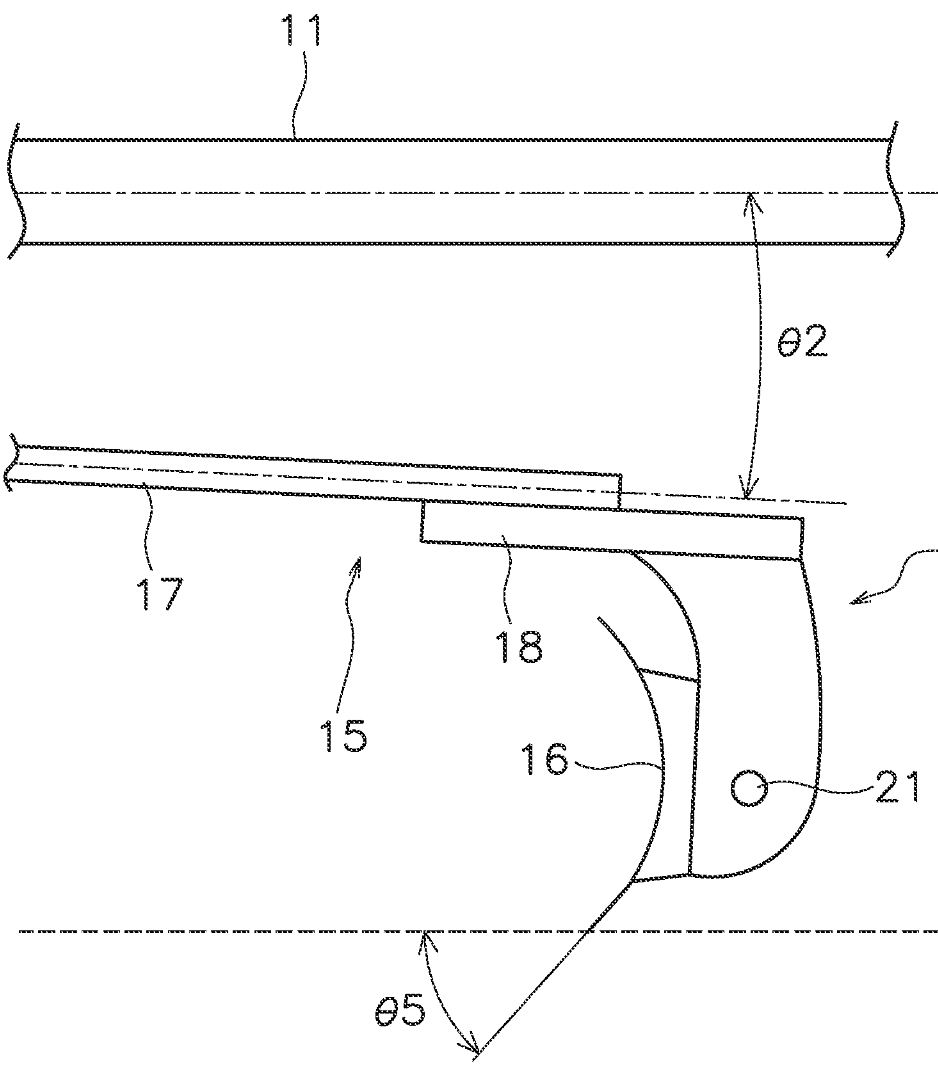


FIG. 6

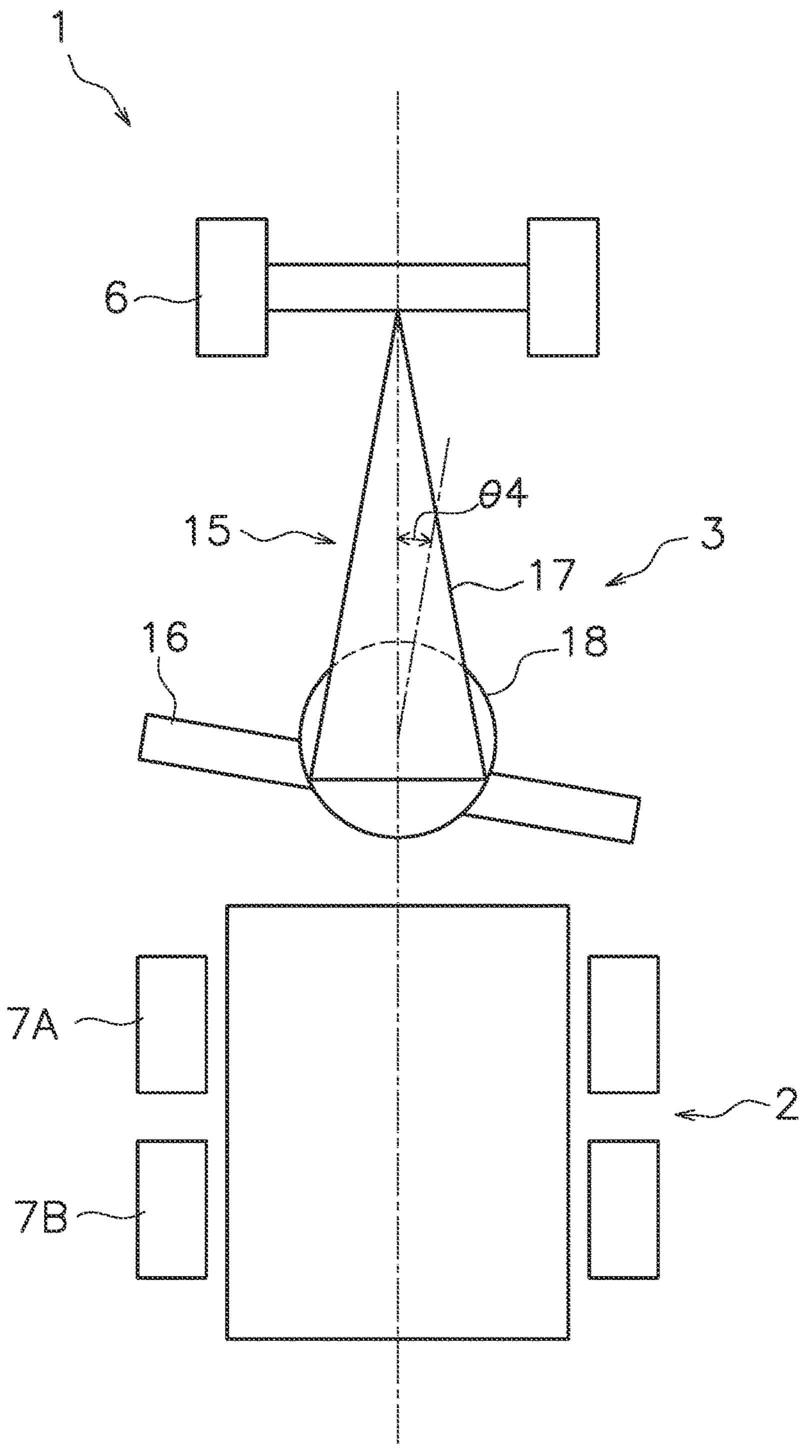


FIG. 7

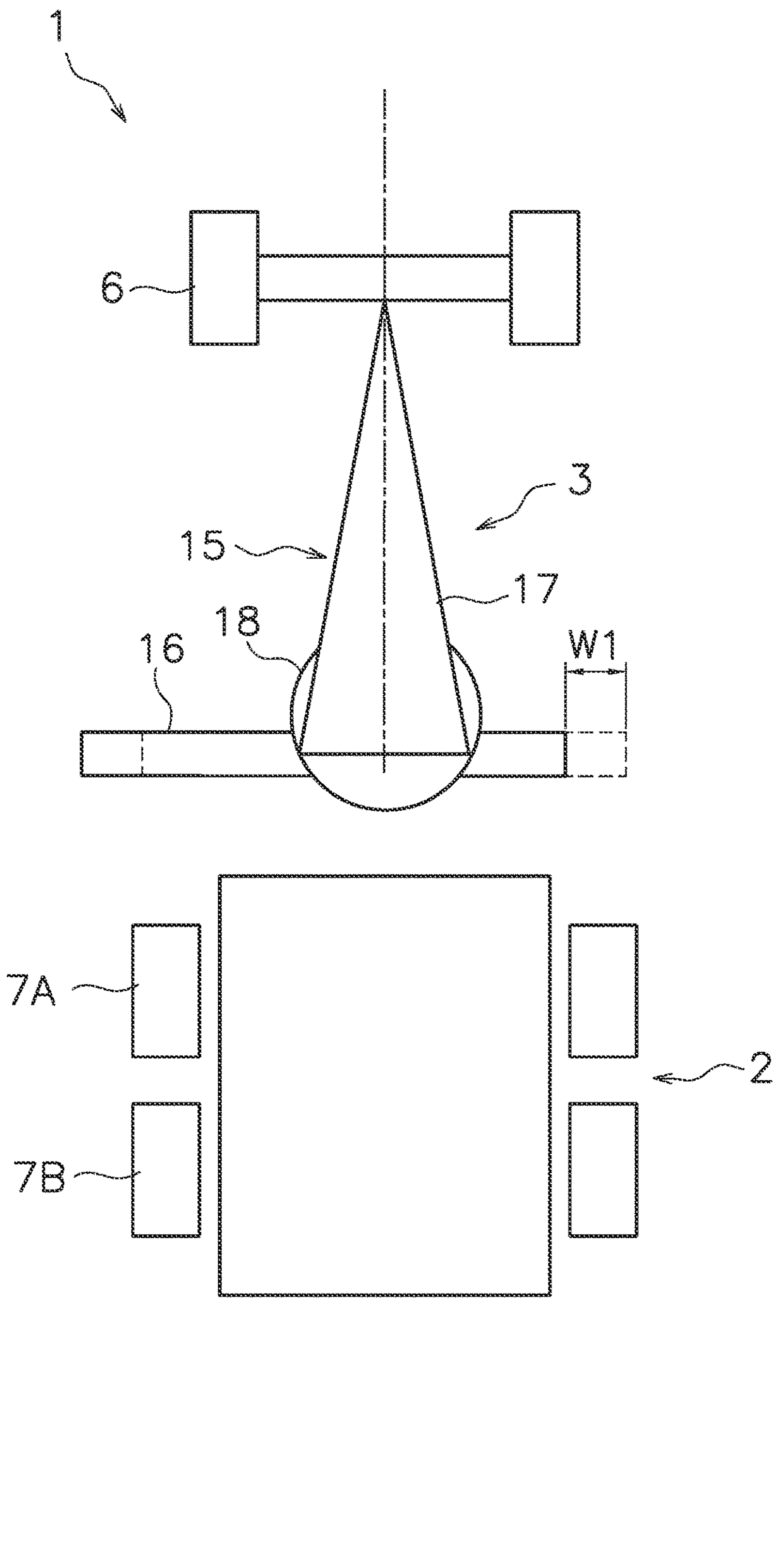


FIG. 8

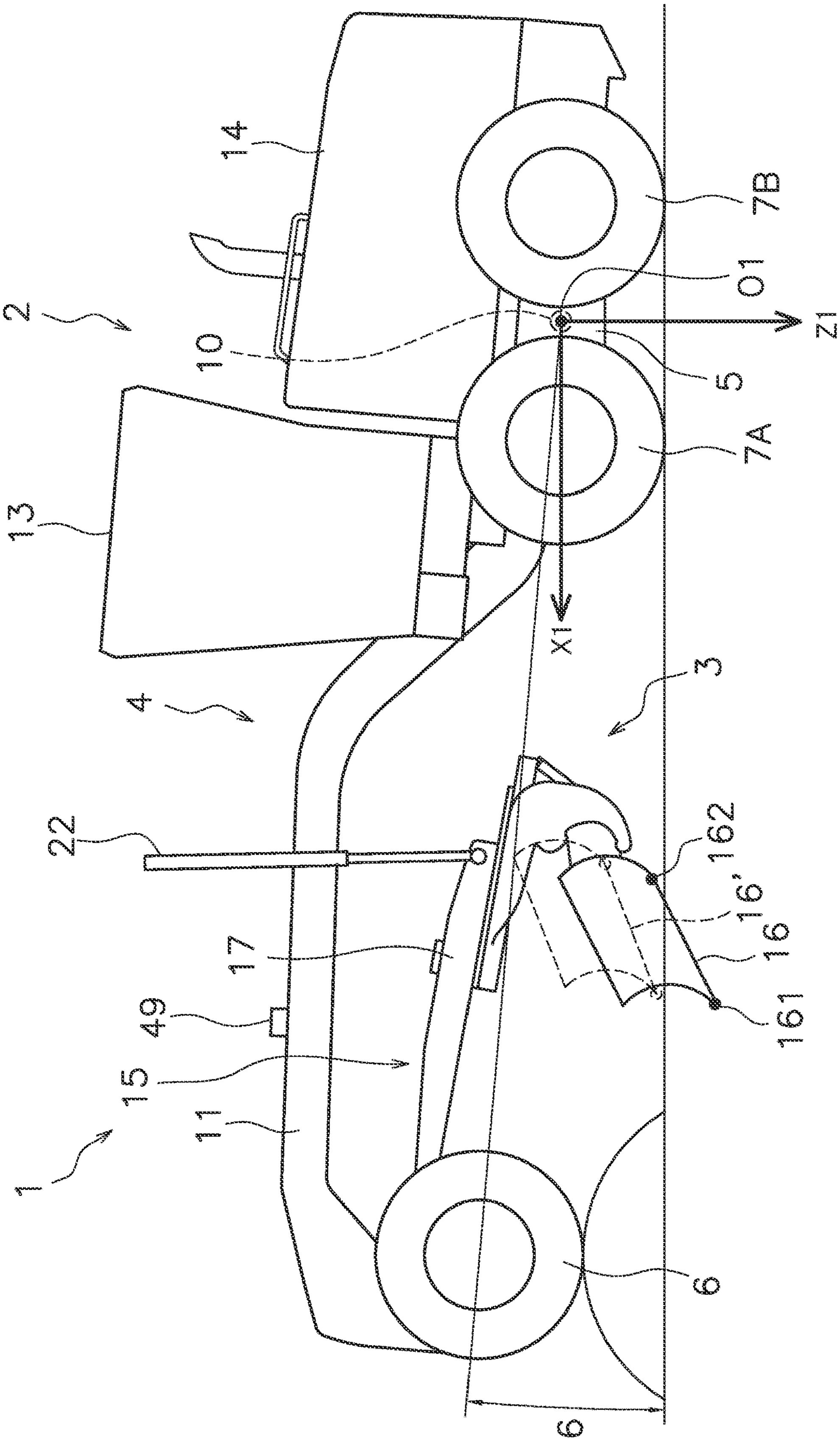


FIG. 9

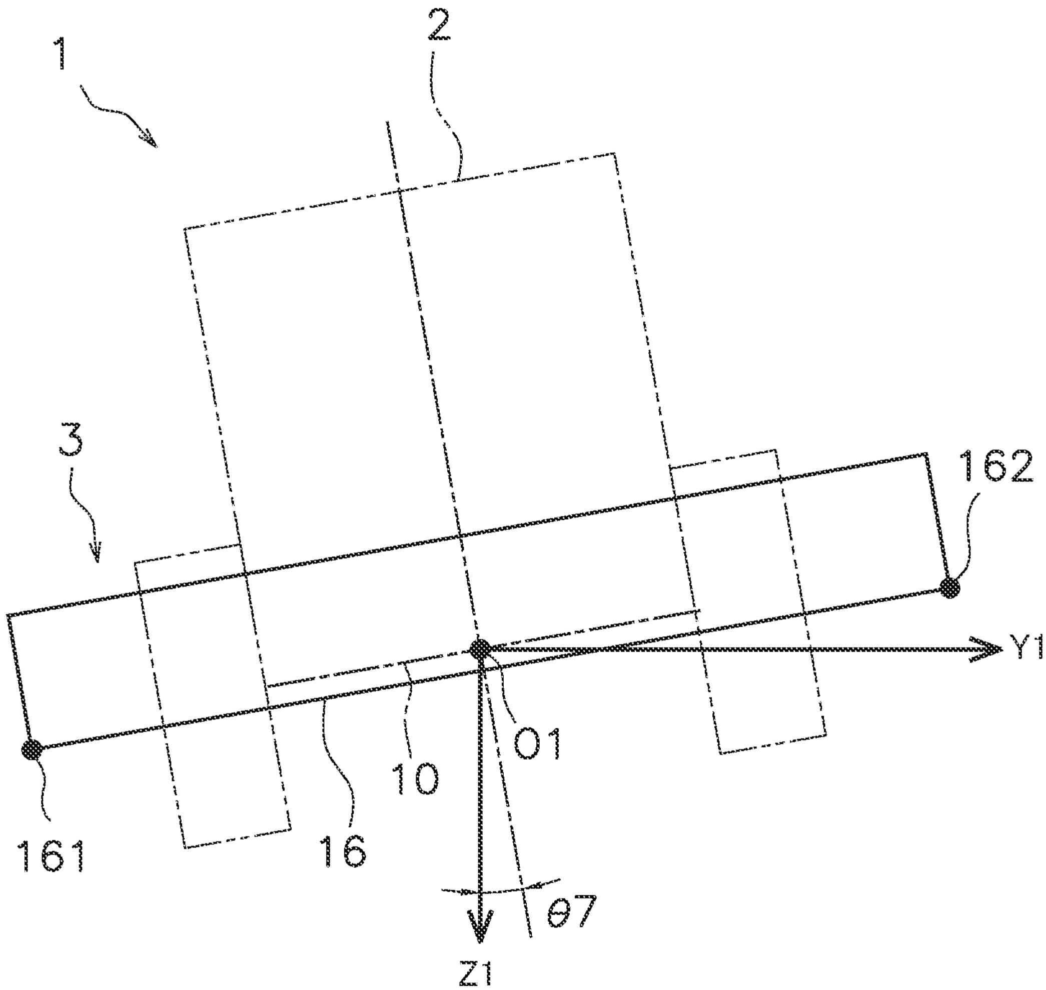


FIG. 10

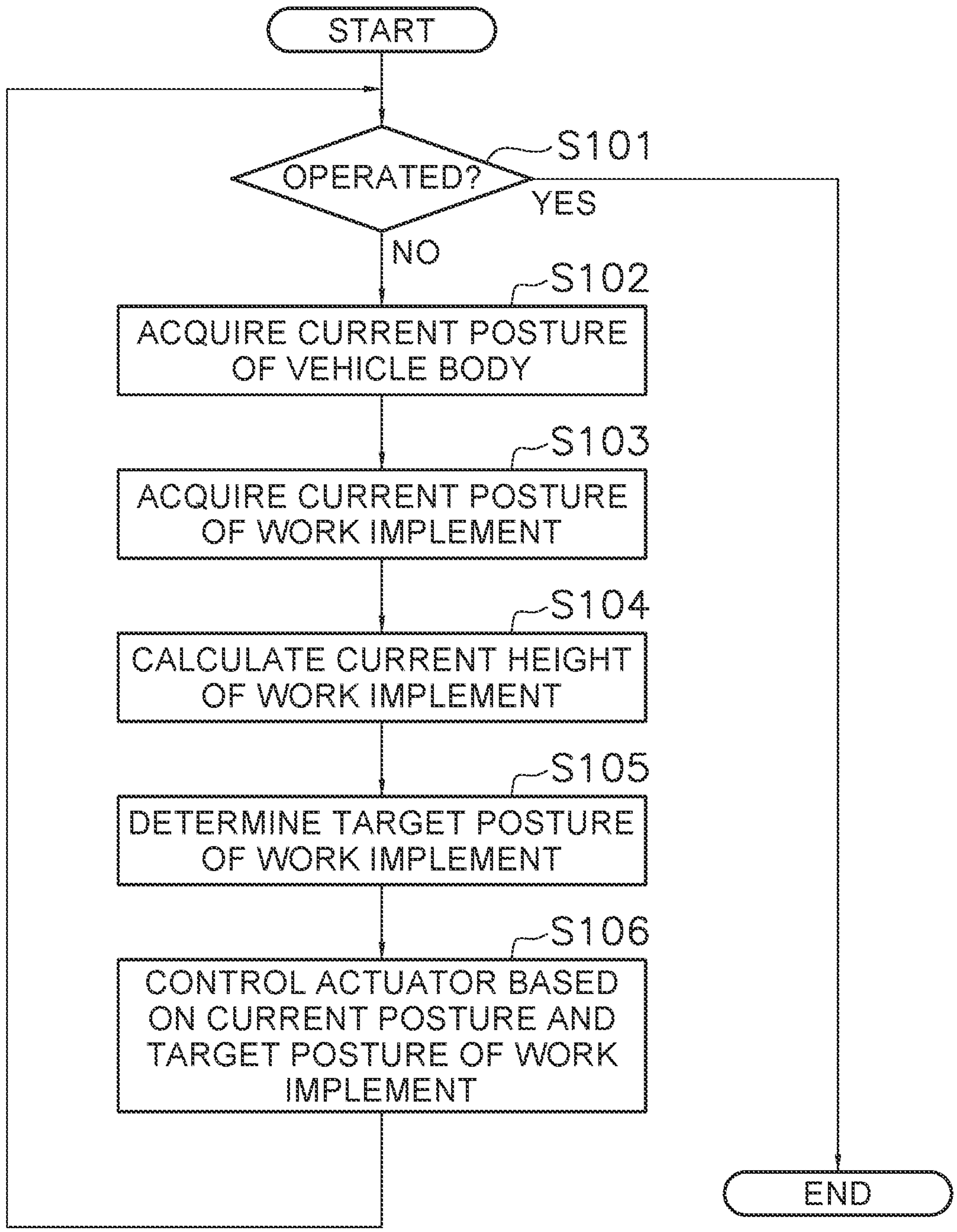

START
OPERATED?
S101
YES
NO
S102
ACQUIRE CURRENT POSTURE OF VEHICLE BODY
S103
ACQUIRE CURRENT POSTURE OF WORK IMPLEMENT
S104
CALCULATE CURRENT HEIGHT OF WORK IMPLEMENT
S105
DETERMINE TARGET POSTURE OF WORK IMPLEMENT
S106
CONTROL ACTUATOR BASED ON CURRENT POSTURE AND TARGET POSTURE OF WORK IMPLEMENT
END

FIG. 11

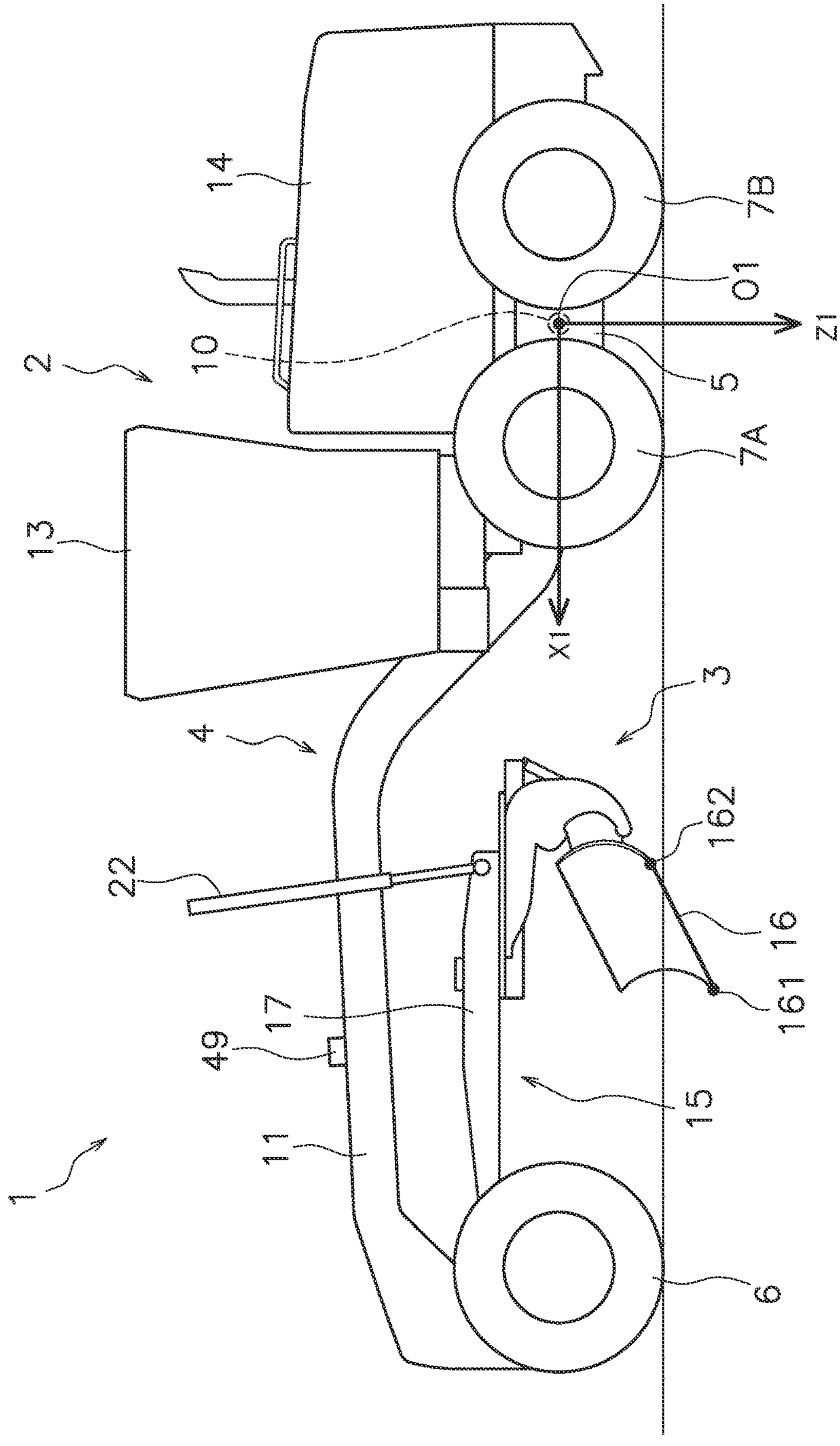


FIG. 12

WORK MACHINE AND METHOD FOR CONTROLLING WORK MACHINE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a U.S. National stage application of International Application No. PCT/JP2022/032445, filed on Aug. 29, 2022. This U.S. National stage application claims priority under 35 U.S.C. § 119(a) to Japanese Patent Application No. 2021-173205, filed in Japan on Oct. 22, 2021, the entire contents of which are hereby incorporated herein by reference.

BACKGROUND

Technical Field

[0002] The present invention relates to a work machine and a method for controlling a work machine.

Background Information

[0003] A work machine includes a vehicle body, a work implement, and an actuator. The actuator is, for example, a hydraulic cylinder. The actuator is driven in response to an operation by an operator, thereby causing the work implement to move. For example, a motor grader includes a blade as the work implement. The motor grader includes a tandem drive and a frame as the vehicle body. The blade is supported by the frame. The frame supports a front wheel so that the front wheel is rotatable. The tandem drive supports a rear wheel. The operator operates an operating lever of the work implement, thereby causing the blade to move up and down.

[0004] In the aforementioned motor grader, the posture of the frame changes when the front wheel travels over an undulation, resulting in a change in height of the blade. A technique that addresses this problem is disclosed in Japanese Patent Application Publication No. 2001-193095. In Japanese Patent Application Publication No. 2001-193095, a controller calculates a change in height of the blade from a relative rotation angle between the frame and the tandem drive. The controller causes the blade to move up and down according to the change in height of the blade. As a result, the blade is maintained at a predetermined height.

SUMMARY

[0005] However, in the motor grader of Japanese Patent Application Publication No. 2001-193095, when the posture of the entire vehicle body including the tandem drive changes, the height direction of the blade with respect to the vehicle body also changes. For example, when the tandem drive is tilted from a horizontal surface, the height of the blade calculated by the controller takes a value different from the actual height of the blade. Therefore, it is difficult to accurately maintain the blade at a predetermined height with respect to the ground. An object of the present invention is to accurately maintain a work implement at a target height even when a work machine travels over a ground with undulations.

[0006] One aspect of the present invention is a work machine that includes a vehicle body, a work implement, an actuator, a vehicle body sensor, a work implement sensor, and a controller. The work implement is supported so as to be movable with respect to the vehicle body. The actuator is connected to the work implement. The actuator causes the work implement to move. The vehicle body sensor detects vehicle body posture data indicative of a posture of the vehicle body. The work implement sensor detects work implement posture data indicative of a posture of the work implement.

[0007] The controller acquires the vehicle body posture data. The controller acquires the work implement posture data. The controller calculates a height of the work implement in a gravity direction from a reference point of the vehicle body based on the vehicle body posture data and the work implement posture data. The controller controls the actuator so that the height of the work implement in the gravity direction is maintained even when the posture of the vehicle body changes.

[0008] Another aspect of the present invention is a method for controlling a work machine. The work machine includes a vehicle body, a work implement, and an actuator. The work implement is supported so as to be movable with respect to the vehicle body. The actuator is connected to the work implement. The actuator causes the work implement to move.

[0009] The method includes acquiring vehicle body posture data indicative of a posture of the vehicle body, acquiring work implement posture data indicative of a posture of the work implement, calculating a height of the work implement in a gravity direction from a reference point of the vehicle body based on the vehicle body posture data and the work implement posture data, and controlling the actuator so that the height of the work implement in the gravity direction is maintained even when the posture of the vehicle body changes.

[0010] According to the present invention, the height of the work implement in the gravity direction is maintained even when the posture of the vehicle body changes. Therefore, even when the work machine travels over a ground with undulations, the height of the work implement is accurately maintained.

BRIEF DESCRIPTION OF DRAWINGS

[0011] FIG. **1** is a side view of a work machine according to an embodiment.

[0012] FIG. **2** is a perspective view of a front part of the work machine.

[0013] FIG. **3** is a schematic diagram illustrating a drive system and a control system of the work machine.

[0014] FIG. **4** is a schematic rear view of the work machine illustrating a posture of a work implement.

[0015] FIG. **5** is a schematic plan view of the work machine illustrating a posture of the work implement.

[0016] FIG. **6** is a schematic enlarged side view of the work machine illustrating a posture of the work implement.

[0017] FIG. **7** is a schematic plan view of the work machine illustrating a posture of the work implement.

[0018] FIG. **8** is a schematic plan view of the work machine illustrating a posture of the work implement.

[0019] FIG. **9** is a schematic side view illustrating a vehicle body coordinate system of the work machine.

[0020] FIG. **10** is a schematic rear view illustrating the vehicle body coordinate system of the work machine.

[0021] FIG. **11** is a flowchart illustrating processes of an automatic control of the work implement.

[0022] FIG. **12** is a schematic side view illustrating the vehicle body coordinate system of the work machine.

DETAILED DESCRIPTION OF EMBODIMENT(S)

[0023] An embodiment of the present invention will be described below with reference to the drawings. FIG. **1** is a side view of a work machine **1** according to the embodiment. FIG. **2** is a perspective view of a front part of the work machine **1**. The work machine **1** according to the present embodiment is a motor grader. As illustrated in FIG. **1**, the work machine **1** includes a vehicle body **2** and a work implement **3**. The work implement **3** is supported so as to be movable with respect to the vehicle body **2**. The vehicle body **2** includes a vehicle body frame **4**, a tandem drive **5**, front wheels **6**, and rear wheels **7**A and **7**B.

[0024] The vehicle body frame **4** supports the front wheels **6** and the work implement **3**. The vehicle body frame **4** includes a front frame **11** and a rear frame **12**. The rear frame **12** is connected to the front frame **11**. The front frame **11** is able to articulate to the left and right with respect to the rear frame **12**. In the following description, the front, rear, left, and right directions mean the front, rear, left, and right directions of the vehicle body **2** while the articulation angle is zero, that is, while the front frame **11** and the rear frame **12** are straight.

[0025] A cab **13** and a power compartment **14** are disposed on the rear frame **12**. An unillustrated operator's seat is disposed in the cab **13**. A drive system which will be described later is disposed in the power compartment **14**. The front frame **11** extends forward from the rear frame **12**. The front wheels **6** are attached to the front frame **11**.

[0026] The tandem drive **5** is connected to the rear frame **12**. The tandem drive **5** supports the rear wheels **7**A and **7**B and drives the rear wheels **7**A and **7**B. The tandem drive **5** includes a rear axis **10** that extends in the left-right direction. The tandem drive **5** supports the rear frame **12** of the vehicle body frame **4** so that the rear frame **12** is swingable about the rear axis **10**. When the front wheels **6** move up and down due to undulations of a road surface that is not graded by the work implement **3**, the vehicle body frame **4** swings about the rear axis **10** (see FIG. **9**.)

[0027] The rear wheels **7**A and **7**B include a pair of first rear wheels **7**A and a pair of second rear wheels **7**B. In FIG. **1**, only the first rear wheel **7**A at the left side and the second rear wheel **7**B at the left side are illustrated. The second rear wheels **7**B are disposed behind the first rear wheels **7**A. The rear axis **10** is disposed between the first rear wheels **7**A and the second rear wheels **7**B. The rear axis **10** serves as the center of swing of the vehicle body frame **4** with respect to the tandem drive **5**.

[0028] The work implement **3** is movably connected to the vehicle body **2**. The work implement **3** includes a supporting member **15** and a blade **16**. The supporting member **15** is movably connected to the vehicle body **2**. The supporting member **15** supports the blade **16**. The supporting member **15** includes a drawbar **17** and a circle **18**. The drawbar **17** and the circle **18** are disposed below the front frame **11**.

[0029] As illustrated in FIG. **2**, the drawbar **17** is connected to a shaft support part **19** of the front frame **11**. The shaft support part **19** is disposed at a front part of the front frame **11**. The drawbar **17** extends rearward from the front part of the front frame **11**. The drawbar **17** is supported so as to be swingable at least in the up-down direction and the left-right direction of the vehicle body **2** with respect to the front frame **11**. For example, the shaft support part **19** includes a ball joint. The drawbar **17** is rotatably connected to the front frame **11** via the ball joint.

[0030] The circle **18** is connected to a rear part of the drawbar **17**. The circle **18** is supported so as to be rotatable with respect to the drawbar **17**. The blade **16** is connected to the circle **18**. The blade **16** is supported by the drawbar **17** via the circle **18**. The blade **16** is supported by the circle **18** so as to be rotatable about a tilt shaft **21**. The tilt shaft **21** extends in the left-right direction. The blade **16** is supported by the circle **18** so as to be slidable in the left-right direction.

[0031] The work machine **1** includes a plurality of actuators **22** to **27** for changing the posture of the work implement **3**. The plurality of actuators **22** to **27** include a plurality of hydraulic cylinders **22** to **26**. The plurality of hydraulic cylinders **22** to **26** are connected to the work implement **3**. The plurality of hydraulic cylinders **22** to **26** extend and contract due to hydraulic pressure. The plurality of hydraulic cylinders **22** to **26** extend and contract, thereby changing the posture of the work implement **3** with respect to the vehicle body **2**. In the following explanation, the extension and contraction of the hydraulic cylinders is referred to as a "stroke motion."

[0032] Specifically, the plurality of hydraulic cylinders **22** to **26** include a left lift cylinder **22**, a right lift cylinder **23**, a drawbar shift cylinder **24**, a blade tilt cylinder **25**, and a blade shift cylinder **26**. The left lift cylinder **22** and the right lift cylinder **23** are disposed apart from each other in the left-right direction. The left lift cylinder **22** is connected to a left part of the drawbar **17**. The right lift cylinder **23** is connected to a right part of the drawbar **17**. The left lift cylinder **22** and the right lift cylinder **23** are connected to the drawbar **17** so as to be swingable to the left and right.

[0033] The left lift cylinder **22** and the right lift cylinder **23** are connected so as to be swingable to the left and right with respect to the front frame **11**. Specifically, the left lift cylinder **22** and the right lift cylinder **23** are connected to the front frame **11** via a lifter bracket **29**. The lifter bracket **29** is connected to the front frame **11**. The lifter bracket **29** supports the left lift cylinder **22** and the right lift cylinder **23** so that the left lift cylinder **22** and the right lift cylinder **23** are swingable to the left and right. Due to the stroke motions of the left lift cylinder **22** and the right lift cylinder **23**, the drawbar **17** swings up and down about the shaft support part **19**. As a result, the blade **16** moves up and down.

[0034] The drawbar shift cylinder **24** is connected to the drawbar **17** and the front frame **11**. The drawbar shift cylinder **24** is connected to the front frame **11** via the lifter bracket **29**. The drawbar shift cylinder **24** is connected so as to be swingable with respect to the front frame **11**. The drawbar shift cylinder **24** is connected so as to be swingable with respect to the drawbar **17**. The drawbar shift cylinder **24** extends diagonally downward from the front frame **11** toward the drawbar **17**. The drawbar shift cylinder **24** extends to the left and right from one side to the opposite side of the front frame **11**. The drawbar **17** swings to the left and right about the shaft support part **19** due to the stroke motion of the drawbar shift cylinder **24**.

[0035] As illustrated in FIG. **1**, the blade tilt cylinder **25** is connected to the circle **18** and the blade **16**. The blade **16** rotates about the tilt shaft **21** due to the stroke motion of the blade tilt cylinder **25**. As illustrated in FIG. **2**, the blade shift cylinder **26** is connected to the circle **18** and the blade **16**.

The blade **16** slides to the left and right with respect to the circle **18** due to the stroke motion of the blade shift cylinder **26**.

[0036] The plurality of actuators **22** to **27** include a rotary actuator **27**. The rotary actuator **27** is connected to the drawbar **17** and the circle **18**. The rotary actuator **27** causes the circle **18** to rotate with respect to the drawbar **17**. As a result, the blade **16** rotates about a rotation axis that extends in the up-down direction.

[0037] FIG. **3** is a schematic diagram illustrating a drive system **8** and a control system **9** of the work machine **1**. As illustrated in FIG. **3**, the work machine **1** includes a drive source **31**, a hydraulic pump **32**, a power transmission device **33**, and a control valve **34**. The drive source **31** is, for example, an internal combustion engine. Alternatively, the drive source **31** may be an electric motor or a hybrid of an internal combustion engine and an electric motor. The hydraulic pump **32** is driven by the drive source **31** to discharge hydraulic fluid.

[0038] The control valve **34** is connected to the hydraulic pump **32** and the plurality of hydraulic cylinders **22** to **26** through a hydraulic circuit. The control valve **34** includes a plurality of valves respectively connected to the plurality of hydraulic cylinders **22** to **26**. The control valve **34** controls the flow rate of hydraulic fluid supplied from the hydraulic pump **32** to the plurality of hydraulic cylinders **22** to **26**.

[0039] In the present embodiment, the rotary actuator **27** is a hydraulic motor. The control valve **34** is connected to the hydraulic pump **32** and the rotary actuator **27** through a hydraulic circuit. The control valve **34** controls the flow rate of hydraulic fluid supplied from the hydraulic pump **32** to the rotary actuator **27**. The rotary actuator **27** may be an electric motor.

[0040] The power transmission device **33** transmits the driving force from the drive source **31** to the rear wheels **7**A and **7**B. The power transmission device **33** may include a torque converter and/or a plurality of speed change gears. Alternatively, the power transmission device **33** may be a transmission such as a hydraulic static transmission (HST) or a hydraulic mechanical transmission (HMT).

[0041] As illustrated in FIG. **3**, the work machine **1** includes an operating device **35** and a controller **36**. The operating device **35** is operable by an operator for changing the posture of the work implement **3**. The posture of the work implement **3** indicates a position and an orientation of the blade **16** with respect to the vehicle body **2**. FIG. **4** is a schematic rear view of the work machine **1** illustrating the posture of the work implement **3**. As illustrated in FIG. **4**, the height of a left end portion **161** and the height of a right end portion **162** of the blade **16** are changed according to an operation of the operating device **35**.

[0042] A yaw angle θ**1**, a pitch angle θ**2**, and a roll angle θ**3** of the drawbar **17** are changed according to an operation of the operating device **35**. FIG. **5** is a schematic plan view of the work machine **1** illustrating the posture of the work implement **3**. As illustrated in FIG. **5**, the yaw angle θ**1** of the drawbar **17** is a tilt angle of the drawbar **17** in the left-right direction with respect to the front-rear direction of the vehicle body **2**. The yaw angle θ**1** of the drawbar **17** may be a tilt angle of the drawbar **17** in the left-right direction with respect to the front-rear direction of the front frame **11**. The position of the blade **16** in the left-right direction changes according to the yaw angle θ**1** of the drawbar **17**.

[0043] FIG. **6** is a schematic side view of the work machine **1** illustrating the posture of the work implement **3**. As illustrated in FIG. **6**, the pitch angle θ**2** of the drawbar **17** is a tilt angle of the drawbar **17** in the up-down direction with respect to the front-rear direction of the vehicle body **2**. As illustrated in FIG. **4**, the roll angle θ**3** of the drawbar **17** is a tilt angle of the drawbar **17** about a roll axis A**1** that extends in the front-rear direction of the vehicle body **2**.

[0044] According to an operation of the operating device **35**, a rotation angle θ**4** of the circle **18**, a tilt angle θ**5** of the blade **16**, and a shift amount W**1** of the blade **16** are changed. FIG. **7** is a schematic plan view of the work machine **1** illustrating the posture of the work implement **3**. As illustrated in FIG. **7**, the rotation angle θ**4** of the circle **18** is the rotation angle θ**4** of the circle **18** with respect to the front-rear direction of the vehicle body **2**. As illustrated in FIG. **6**, the tilt angle θ**5** of the blade **16** is a tilt angle of the blade **16** about the tilt shaft **21** that extends in the left-right direction. FIG. **8** is a schematic plan view of the work machine **1** illustrating the posture of the work implement **3**. As illustrated in FIG. **8**, the shift amount W**1** of the blade **16** is an amount by which the blade **16** slides in the left-right direction with respect to the circle **18**.

[0045] The operating device **35** includes a plurality of operating members **41** to **46**. The plurality of operating members **41** to **46** are provided respectively corresponding to the left lift cylinder **22**, the right lift cylinder **23**, the drawbar shift cylinder **24**, the blade tilt cylinder **25**, the blade shift cylinder **26**, and the rotary actuator **27**.

[0046] The plurality of operating members **41** to **46** include a left lift lever **41**, a right lift lever **42**, a drawbar shift lever **43**, a rotation lever **44**, a blade tilt lever **45**, and a blade shift lever **46**. The left lift cylinder **22** extends and contracts according to an operation of the left lift lever **41**. The right lift cylinder **23** extends and contracts according to an operation of the right lift lever **42**.

[0047] The drawbar shift cylinder **24** extends and contracts according to an operation of the drawbar shift lever **43**. The rotary actuator **27** rotates according to an operation of the rotation lever **44**. The blade tilt cylinder **25** extends and contracts according to an operation of the blade tilt lever **45**. The blade shift cylinder **26** extends and contracts according to an operation of the blade shift lever **46**. Each of the plurality of operating members **41** to **46** outputs a signal indicative of the operation by the operator for each of the operating member **41** to **46**.

[0048] The controller **36** controls the drive source **31** and the power transmission device **33**, thereby causing the work machine **1** to travel. Further, the controller **36** controls the hydraulic pump **32** and the control valve **34**, thereby causing the work implement **3** to move. The controller **36** includes a processor **37** and a storage device **38**. The processor **37** is, for example, a CPU and executes a program for controlling the work machine **1**. The storage device **38** includes a memory such as a RAM or a ROM, and an auxiliary storage device such as an SSD or an HDD. The storage device **38** stores programs and data for controlling the work machine **1**.

[0049] As illustrated in FIG. **3**, the work machine **1** includes a work implement sensor **48** for detecting the posture of the work implement **3** described above. The work implement sensor **48** includes a plurality of sensors S**1** to S**8**. The plurality of sensors S**1** to S**8** are, for example, magnetic sensors. The plurality of sensors S**1** to S**8** may be sensors of another type such as an optical sensor. The plurality of sensors **S1** to **S5** detect stroke lengths of the plurality of hydraulic cylinders **22** to **26** described above. The plurality of sensors **S1** to **S5** include a left lift sensor **S1**, a right lift sensor **S2**, a drawbar shift sensor **S3**, a blade tilt sensor **S4**, and a blade shift sensor **S5**.

[0050] The left lift sensor **S1** detects a stroke length of the left lift cylinder **22**. The right lift sensor **S2** detects a stroke length of the right lift cylinder **23**. The drawbar shift sensor **S3** detects a stroke length of the drawbar shift cylinder **24**. The blade tilt sensor **S4** detects a stroke length of the blade tilt cylinder **25**. The blade shift sensor **S5** detects a stroke length of the blade shift cylinder **26**.

[0051] The plurality of sensors **S1** to **S8** include a rotation sensor **S6**. The rotation sensor **S6** detects the rotation angle θ**4** of the circle **18**. The plurality of sensors **S1** to **S8** output signals indicative of the stroke lengths and the rotation angle θ**4** detected by the respective sensors. The plurality of sensors **S1** to **S8** include a left cylinder angle sensor **S7** and a right cylinder angle sensor **S8**. The left cylinder angle sensor **S7** detects a swing angle of the left lift cylinder **22** in the left-right direction with respect to the lifter bracket **29**. The right cylinder angle sensor **S8** detects a swing angle of the right lift cylinder **23** in the left-right direction with respect to the lifter bracket **29**. By means of these sensors **S1** to **S8**, a posture of the drawbar **17** with respect to the vehicle body **2** is detected and a posture of the blade **16** with respect to the drawbar **17** is detected. That is, the posture of the blade **16** with respect to the vehicle body **2** is detected by these sensors **S1** to **S8**.

[0052] The work machine **1** includes a vehicle body sensor **49**. The vehicle body sensor **49** is, for example, an inertial measurement unit (IMU). The vehicle body sensor **49** detects vehicle body posture data indicative of a posture of the vehicle body **2**. The vehicle body posture data includes a pitch angle and a roll angle of the vehicle body **2**. Note that the vehicle body sensor **49** is not limited to the IMU. The vehicle body sensor **49** may be any means that measures the pitch angle and the roll angle of the vehicle body **2**, and may be an inclinometer, for example.

[0053] The vehicle body sensor **49** is attached to the vehicle body frame **4**. Therefore, as illustrated in FIG. **9**, a pitch angle θ**6** of the vehicle body **2** is a tilt angle of the vehicle body frame **4** in the up-down direction with respect to a horizontal direction. As illustrated in FIG. **10**, a roll angle θ**7** of the vehicle body **2** is a tilt angle of the vehicle body frame **4** in the left-right direction with respect to the horizontal direction. Note that the vehicle body sensor **49** may be attached to another place on the vehicle body **2** where the position relative to the vehicle body frame **4** does not change, instead of the vehicle body frame **4**. For example, the vehicle body sensor **49** may be disposed on any of other places excluding the tandem drive **5** or the drawbar **17** where the position relative to the vehicle body frame **4** changes.

[0054] The controller **36** acquires work implement posture data indicative of the posture of the work implement **3** with respect to the vehicle body **2** based on a signal from the work implement sensor **48**. The work implement posture data includes the height of the left end portion **161** of the blade **16**, the height of the right end portion **162**, the yaw angle θ**1** of the drawbar **17**, the pitch angle θ**2**, the roll angle θ**3**, the rotation angle θ**4** of the circle **18**, the tilt angle θ**5** of the blade **16**, and the shift amount W**1** of the blade **16** as described above. The controller **36** acquires the vehicle body posture data based on a signal from the vehicle body sensor **49**. The controller **36** controls the plurality of actuators **22** to **27** according to the operations of the plurality of operating members **41** to **46**, thereby changing the posture of the work implement **3**.

[0055] The controller **36** performs an automatic control of the work implement **3** based on the aforementioned vehicle body posture data and work implement posture data. The controller **36** controls the left lift cylinder **22** and the right lift cylinder **23** so as to maintain the work implement **3** at a target height under the automatic control of the work implement **3**. Processes of the automatic control of the work implement **3** will be described below. FIG. **11** is a flowchart illustrating the processes of the automatic control of the work implement **3**.

[0056] As illustrated in FIG. **11**, in step S**101**, the controller **36** determines whether the operating device **35** is being operated. The controller **36** may determine that the operating device **35** is no longer operated when an operation input on the operating device **35** is not performed for a certain period of time. When at least one of the aforementioned operating members **41** to **46** is being operated, the controller **36** does not perform the automatic control the work implement **3**. Therefore, the controller **36** controls the plurality of actuators **22** to **27** according to the operations of the plurality of operating members **41** to **46**, thereby changing the posture of the work implement **3**. When the operating members **41** to **46** are not being operated, the process proceeds to step S**102**.

[0057] In step S**102**, the controller **36** acquires a current posture of the vehicle body **2**. Here, the controller **36** acquires the current posture of the vehicle body **2** from the vehicle body posture data. In step S**103**, the controller **36** acquires a current posture of the work implement **3**. Here, the controller **36** acquires the current posture of the work implement **3** from the work implement posture data.

[0058] In step S**104**, the controller **36** calculates a current height of the work implement **3**. The controller **36** calculates the height of the work implement **3** based on the vehicle body posture data and the work implement posture data. For example, the height of the work implement **3** is the height of the left end portion **161** and the height of the right end portion **162** of the blade **16**. Here, the height of the work implement **3** means the height in the gravity direction from an origin O**1** taking the origin O**1** of the vehicle body **2** illustrated in FIG. **12** as a reference point. For example, the height of the work implement **3** means the height of the work implement **3** in the gravity direction from a horizontal surface including the origin O**1** of the vehicle body **2**.

[0059] As illustrated in FIG. **12**, in a case where the work machine **1** performs work while traveling forward, the origin O**1** of the vehicle body **2** is positioned on the tandem drive **5**. For example, the origin O**1** of the vehicle body **2** is positioned at the center of the rear axis **10** in the left-right direction. In FIG. **12**, a Z**1** axis indicates the gravity direction. An X**1** axis indicates the front-rear direction of the vehicle body **2** that is perpendicular to the gravity direction. In FIG. **4**, a Y**1** axis indicates the left-right direction of the vehicle body **2** that is perpendicular to the gravity direction. The posture of the vehicle body **2** changes about the origin O**1** of the vehicle body **2**. For example, as illustrated in FIG. **9**, the pitch angle θ**6** of the vehicle body **2** changes about the origin O**1**. As illustrated in FIG. **10**, the roll angle θ**7** of the vehicle body **2** changes about the origin O**1**.

[0060] In step S**105**, the controller **36** determines a target posture of the work implement **3**. The controller **36** calculates the target posture of the work implement **3** so that the height of the work implement **3** is the target height. Note that the controller **36** stores, as the target height, the height of the work implement **3** when it is determined that the operating device **35** is no longer operated. For example, the controller **36** calculates a target pitch angle and a target roll angle of the drawbar **17** so that the height of the work implement **3** is the target height.

[0061] In step S**106**, the controller **36** controls at least one of the actuators **22** to **27** so that the height of the work implement **3** is the target height. For example, the controller **36** controls the lift cylinders **22** and **23** and the drawbar shift cylinder **24** so that the pitch angle θ**2** of the drawbar **17** is the target pitch angle and the roll angle θ**3** of the drawbar **17** is the target roll angle.

[0062] In this case, the controller **36** controls the lift cylinders **22** and **23** and the drawbar shift cylinder **24** so that a position of the blade **16** in the left-right direction does not change. That is, in the work machine **1**, due to the extension and contraction of the lift cylinders **22** and **23**, not only the height direction of the blade **16** but also the position of the blade **16** in the left and right direction changes. Therefore, the controller **36** controls the drawbar shift cylinder **24** so as to offset a change in position of the blade **16** in the left-right direction due to the extension and contraction of the lift cylinders **22** and **23**. As a result, the height of the work implement **3** is maintained at the target height and the position of the work implement **3** in the left-right direction is maintained.

[0063] The controller **36** controls the actuators **22** to **27** so that the work implement **3** is maintained at the target height by repeating the aforementioned processes of steps S**102** to S**106**. When the operating device **35** is operated during the automatic control, the controller **36** ends the automatic control (step S**101**).

[0064] With the work machine **1** according to the present embodiment described above, the work implement **3** is maintained at the target height of the work implement **3** by the automatic control. The target height is the height in the gravity direction from the origin O**1** of the vehicle body **2**, and the work implement **3** is maintained at the target height of the work implement **3** even when the posture of the vehicle body **2** changes. Therefore, the work implement **3** is accurately maintained at the target height even when the work machine **1** travels on a ground with undulations.

[0065] For example, in FIG. **9**, the blade **16'** depicted with a dashed line indicates the position of the blade **16** when the automatic control is not performed. As illustrated in FIG. **9**, in a case where the automatic control is not performed, the blade **16'** is raised above the position of the blade **16** illustrated in FIG. **12**, when the front wheels **6** travel over a bump. However, in the work machine **1** according to the present embodiment, the blade **16** is maintained at the target height of the work implement **3** in the gravity direction by the automatic control as illustrated in FIG. **9**. Therefore, even if the front wheels **6** travel over a bump, the controller **36** controls the actuators **22** to **27**, thereby causing the blade **16** to be accurately maintained at the target height.

[0066] Although one embodiment of the present invention has been described above, the present invention is not limited to the above embodiment and various modifications can be made without departing from the gist of the invention.

[0067] The work machine **1** is not limited to a motor grader and may be another work machine such as a bulldozer. In another work machine such as a bulldozer, a position of the origin O**1** can be set according to a structural characteristic of the work machine. The configuration of the work implement **3** is not limited to that of the above embodiment and may be changed. For example, the work implement **3** may include a blade and a lift arm. The lift arm may support the blade and be connected to the vehicle body. The parameters indicative of the posture of the work implement **3** are not limited to those of the above embodiment and may be changed.

[0068] The plurality of operating members **41** to **46** are not limited to those of the above embodiment and may be changed. For example, the operating member is not limited to a lever and may be another member such as a joystick, a switch, or a touch screen. The plurality of operating members **41** to **46** may directly operate the respective actuators **22** to **27**.

[0069] The sensor for detecting the posture of the work implement **3** is not limited to that of the above embodiment and may be changed. The sensors S**1** to S**5** may directly detect angles, instead of the stroke lengths. The work implement sensor **48** may include an inertial measurement unit (IMU). The IMU may be mounted on the drawbar **17**. The posture of the drawbar **17** may be detected by the IMU. Either of the left cylinder angle sensor S**7** or the right cylinder angle sensor S**8** may be omitted.

[0070] The operating device **35** may include an operating member for the automatic control. The controller **36** may start the automatic control according to an operation of the operating member for the automatic control. The controller **36** may end the automatic control according to an operation of the operating member for the automatic control. According to an operation of the operating member for the automatic control, the controller **36** may store, as the target height, the height of the work implement **3** when the automatic control is started.

[0071] In the aforementioned automatic control, in a case where the posture (angle) of the vehicle body **2** or the change in posture (angular velocity) exceeds a predetermined value, a detection error of the sensors S**1** to S**8** may be large. Further, in a case where a sudden acceleration or a sudden deceleration that exceeds a predetermined amount occurs, a reaction speed of the sensors S**1** to S**8** may not be able to keep up. In this case, the controller **36** may temporarily release the automatic control. The controller **36** may temporarily release the automatic control when a difference between the target posture and the current posture of the work implement **3** exceeds a predetermined threshold.

[0072] In the aforementioned embodiment, the automatic control when the work machine **1** performs work while traveling forward has been described, but the present invention may be applied when the work machine **1** performs work while traveling backward. In this case, the origin O of the vehicle body **2** may be a center position between the left and right front wheels **6**.

[0073] In the aforementioned embodiment, the controller **36** acquires the posture of the work implement **3** when the operating device **35** is not operated for a certain period of time and acquires the height of the work implement **3** at that time as the current height of the work implement **3**. However, the method for acquiring the current height of the work implement **3** is not limited to this and may be changed. For example, the controller **36** may acquire the posture of the work implement **3** when the operating device such as a push button is operated and acquire the height of the work implement **3** at that time as the current height of the work implement **3**. A switch for increasing or decreasing the acquired height of the work implement **3** by a predetermined amount may be provided. The controller **36** may change the target posture of the work implement **3** according to an operation of the switch. As a result, the target posture of the work implement **3** can be finely adjusted.

[0074] According to the present invention, the work implement is accurately maintained at the target height even when the work machine travels on a ground with undulations.

1. A work machine comprising:
a vehicle body;
a work implement supported so as to be movable with respect to the vehicle body;
an actuator connected to the work implement, the actuator being configured to cause the work implement to move;
a vehicle body sensor configured to detect vehicle body posture data indicative of a posture of the vehicle body;
a work implement sensor configured to detect work implement posture data indicative of a posture of the work implement; and
a controller configured to
acquire the vehicle body posture data,
acquire the work implement posture data,
calculate a height of the work implement in a gravity direction from a reference point of the vehicle body based on the vehicle body posture data and the work implement posture data, and
control the actuator so that the height of the work implement in the gravity direction is maintained even when the posture of the vehicle body changes.

2. The work machine according to claim **1**, wherein
the vehicle body includes
a front wheel,
a vehicle body frame that supports the front wheel and the work implement,
a rear wheel, and
a tandem drive that supports the rear wheel, the tandem drive includes a rear axis extending in a left-right direction, and the tandem drive supports the vehicle body frame so that the vehicle body frame is swingable about the rear axis, and
the controller is configured to maintain the height of the work implement in the gravity direction even when the vehicle body frame swings about the rear axis with respect to the tandem drive.

3. The work machine according to claim **2**, wherein
the reference point of the vehicle body is disposed on the tandem drive.

4. The work machine according to claim **1**, further comprising:
an operating device configured to be operated by an operator,
the controller being configured to
acquire an operation signal indicative of an operation of the operating device,
control the actuator so that the work implement moves according to the operation of the operating device,
store, as a target height, a height of the work implement when the operation of the operating device is finished, and
control the actuator so that the height of the work implement in the gravity direction is maintained at the target height even when the posture of the vehicle body changes.

5. The work machine according to claim **1**, wherein
the controller is configured to control the actuator so that a position of the work implement in the left-right direction is maintained even when the posture of the vehicle body changes.

6. A method for controlling a work machine that includes a vehicle body, a work implement supported so as to be movable with respect to the vehicle body, and an actuator connected to the work implement and configured to cause the work implement to move, the method comprising:
acquiring vehicle body posture data indicative of a posture of the vehicle body;
acquiring work implement posture data indicative a posture of the work implement;
calculating a height of the work implement in a gravity direction from a reference point of the vehicle body based on the vehicle body posture data and the work implement posture data; and
controlling the actuator so that the height of the work implement in the gravity direction is maintained, even when the posture of the vehicle body changes.

7. The method according to claim **6**, wherein
the vehicle body includes
a front wheel,
a vehicle body frame that supports the front wheel and the work implement,
a rear wheel, and
a tandem drive that supports the rear wheel, the tandem drive includes a rear axis extending in a left-right direction, and the tandem drive supports the vehicle body frame so that the vehicle body frame is swingable about the rear axis, and
the height of the work implement in the gravity direction is maintained even when the vehicle body frame swings about the rear axis with respect to the tandem drive.

8. The method according to claim **7**, wherein
the reference point of the vehicle body is disposed on the tandem drive.

9. The method according to claim **6**, further comprising:
acquiring an operation signal indicative of an operation of the operating device configured to be operated by an operator;
controlling the actuator so that the work implement moves according to the operation of the operating device;
storing, as a target height, the height of the work implement when the operation of the operating device is finished; and
controlling the actuator so that the height of the work implement in the gravity direction is maintained at the target height even when the posture of the vehicle body changes.

10. The method according to claim **6**, further comprising:
controlling the actuator so that a position of the work implement in the left-right direction is maintained even when the posture of the vehicle body changes.

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