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(54) **DRIVE SYSTEM OF WORKING MACHINE, WORKING MACHINE, CONTROL DEVICE OF WORKING MACHINE, METHOD OF CONTROLLING WORKING MACHINE, CONTROL PROGRAM FOR A WORKING MACHINE**

(57) A drive system of a working machine includes: an attachment including first and second members; a drive unit configured to drive the attachment, and a control device configured to control the drive unit. The control device stores positional relationship information indicating relationship between (i) first and second angular positions of the first and second members and (ii) positional relationship between a vehicle body and the attachment. The control device performs: an acquisition pro-

cess in which the first and second angular positions are acquired; a calculation process in which positional relationship is calculated by applying the first and second angular positions to the positional relationship information; and a coping process in which a measure is taken to avoid interference between the attachment and the vehicle body if the positional relationship indicates that the shortest distance between the attachment and the vehicle body is less than a predetermined value.

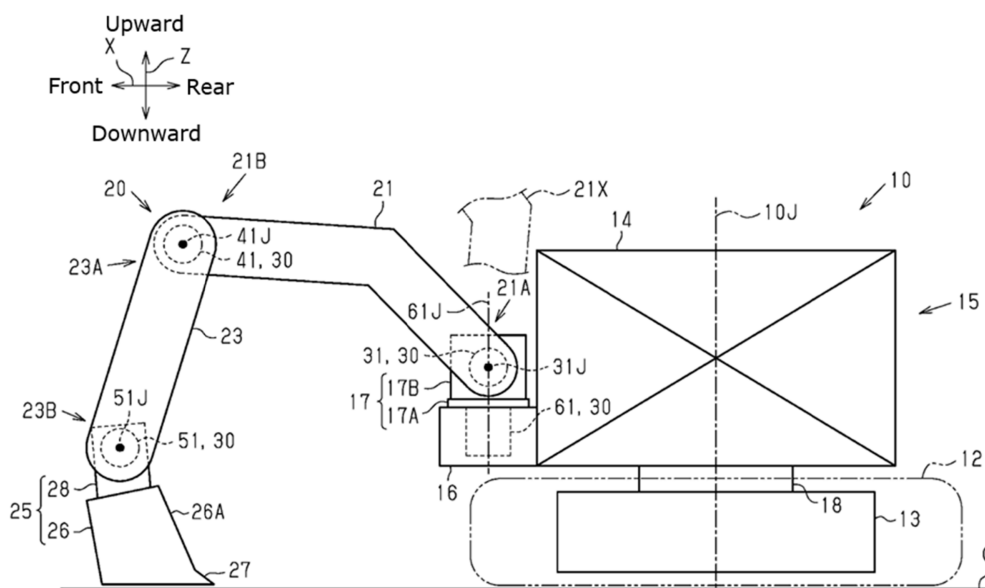


Fig.1

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Description

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is based on and claims the benefit of priority from Japanese Patent Application Serial No. 2025-062505 (filed on April 4, 2025), the contents of which are hereby incorporated by reference in their entirety.

TECHNICAL FIELD

[0002] The present disclosure relates to a drive system of a working machine, a working machine, a control device of a working machine, a method of controlling a working machine, and a control program for controlling a working machine.

BACKGROUND

[0003] Japanese Patent Application Publication No. 2010-174615 ("the '615 Publication") discloses an excavator including a vehicle body and an attachment. The attachment includes a swing bracket, a boom, an arm and a bucket. The vehicle body includes a passenger seat for the operator. The swing bracket is connected to the vehicle body. The swing bracket rotates about an axis extending upward and downward with respect to the vehicle body. The boom is connected to the swing bracket. The boom rotates about an axis that intersects the axis of the swing bracket. The arm is coupled to the front end of the boom. The arm rotates about an axis parallel to the axis of the boom. The bucket is coupled to the front end of the arm. The bucket rotates about an axis parallel to the axis of the boom.

[0004] For the excavator such as disclosed in the '615 Publication, it is desirable to have a wide working range. For example, the rotating elements included in the attachment, such as the boom and arm, are requested to have a wide range of motion. However, if the range of motion of the respective rotating elements is increased, the attachment may possibly reach the vicinity of the vehicle body during its operation. In some cases, the attachment may collide with the vehicle body.

SUMMARY

[0005] To solve the above-described problem, a drive system of a working machine includes: an attachment having: a first member rotatably connected to a vehicle body of the working machine; and a second member rotatably connected to the first member; a drive unit having: a first drive device configured to drive the first member; and a second drive device configured to drive the second member; a first sensor configured to detect a first angular position indicating an angular position of the first member; a second sensor configured to detect a second angular position indicating an angular position of

the second member; and a control device configured to perform drive control to control the drive unit. The control device performs: an acquisition process in which the first and second angular positions are acquired while the drive control is being performed; and a coping process in which a measure is taken to avoid interference between the attachment and the vehicle body based on the first and second angular positions acquired in the acquisition process.

[0006] The above-described drive system of a working machine takes measures to avoid interference between the attachment and the vehicle body based on the first and second angular positions. This can prevent the attachment from colliding with the vehicle body.

[0007] In the drive system of a working machine, the control device may, in the coping process, control the first drive device such that the first member stops moving and control the second drive device such that the second member stops moving.

[0008] In the drive system of a working machine, the control device may: store in advance positional relationship information indicating relationship between (i) the first and second angular positions and (ii) positional relationship between the vehicle body and the attachment; perform a calculation process in which the positional relationship is calculated by applying the first and second angular positions acquired in the acquisition process to the positional relationship information; and perform the coping process if the positional relationship calculated in the calculation process indicates that a shortest distance between the attachment and the vehicle body is less than a predetermined value.

[0009] In the drive system of a working machine, the positional relationship information may represent relationship between (i) the first and second angular positions and (ii) an index value indicating whether the shortest distance is less than the predetermined value, and, in the calculation process, the control device may calculate the index value as the positional relationship by applying the first and second angular positions acquired in the acquisition process to the positional relationship information.

[0010] In the drive system of a working machine, the positional relationship information may include model information that simulates the working machine in a virtual coordinate system. The model information may include: vehicle body coordinate information representing position coordinates of various portions of the vehicle body with the vehicle body being placed at a predetermined reference position in the virtual coordinate system; a first relational equation representing relationship between (i) first coordinate information indicating position coordinates of various portions of the first member and (ii) the first angular position, with the vehicle body being placed at the reference position; and a second relational equation representing relationship between (I) second coordinate information indicating position coordinates of various portions of the second member and (II) the first

and second angular positions, with the vehicle body being placed at the reference position. In the calculation process, the control device may apply the first angular position to the first relational equation to calculate the first coordinate information, apply the first and second angular positions to the second relational equation to calculate the second coordinate information, and calculate the shortest distance as the positional relationship based on the calculated first and second coordinate information and the vehicle body coordinate information.

[0011] In the drive system of a working machine, the first drive device may be driven by a first electric motor, and the second drive device may be driven by a second electric motor. In the drive system of a working machine, the first member may be a swing bracket configured to rotate about a first axis extending upwards and downward relative to the vehicle body, and the second member may be a boom configured to rotate about a second axis intersecting the first axis.

[0012] In the drive system of a working machine, the attachment may include: an arm rotatably connected to the boom, the arm being configured to rotate about a third axis parallel to the second axis; and a working member rotatably connected to the arm, the working member being configured to rotate about a fourth axis parallel to the second axis. The drive unit may include: a third drive device configured to be driven by a third electric motor, the third drive device being configured to drive the arm; and a fourth drive device configured to be driven by a fourth electric motor, the fourth drive device being configured to drive the working member. The drive system may include: a third sensor configured to detect a third angular position indicating an angular position of the arm; and a fourth sensor configured to detect a fourth angular position indicating an angular position of the working member. The control device may: store in advance positional relationship information indicating relationship between (i) the first, second, third and fourth angular positions and (ii) positional relationship between the vehicle body and the attachment; in the acquisition process, acquire the first, second, third and fourth angular positions; perform a calculation process in which the positional relationship is calculated by applying the first, second, third and fourth angular positions acquired in the acquisition process to the positional relationship information; and perform the coping process if the positional relationship calculated in the calculation process indicates that a distance between the attachment and the vehicle body is less than a predetermined value.

[0013] To solve the above-described problem, a working machine includes: a vehicle body; an attachment having: a first member rotatably connected to the vehicle body; and a second member rotatably connected to the first member; a drive unit having: a first drive device configured to drive the first member; and a second drive device configured to drive the second member; a first sensor configured to detect a first angular position indicating an angular position of the first member; a second

sensor configured to detect a second angular position indicating an angular position of the second member; and a control device configured to perform drive control to control the drive unit. The control device performs: an acquisition process in which the first and second angular positions are acquired while the drive control is being performed; and a coping process in which a measure is taken to avoid interference between the attachment and the vehicle body based on the first and second angular positions acquired in the acquisition process.

[0014] The above-described working machine takes measures to avoid interference between the attachment and the vehicle body based on the first and second angular positions. This can prevent the attachment from colliding with the vehicle body.

[0015] To solve the above-described problem, a control device of a working machine is provided and applied to a working machine including: an attachment having: a first member rotatably connected to a vehicle body; and a second member rotatably connected to the first member; a drive unit having: a first drive device configured to drive the first member; and a second drive device configured to drive the second member; a first sensor configured to detect a first angular position indicating an angular position of the first member; and a second sensor configured to detect a second angular position indicating an angular position of the second member. The control device performs: an acquisition process in which the first and second angular positions are acquired while drive control is being performed to control the drive unit; and a coping process in which a measure is taken to avoid interference between the attachment and the vehicle body based on the first and second angular positions acquired in the acquisition process.

[0016] The above-described control device takes measures to avoid interference between the attachment and the vehicle body based on the first and second angular positions. This can prevent the attachment from colliding with the vehicle body.

[0017] The control device of a working machine may: store in advance positional relationship information indicating relationship between (i) the first and second angular positions and (ii) positional relationship between the vehicle body and the attachment; perform a calculation process in which the positional relationship is calculated by applying the first and second angular positions acquired in the acquisition process to the positional relationship information; and perform the coping process if the positional relationship calculated in the calculation process indicates that a shortest distance between the attachment and the vehicle body is less than a predetermined value.

[0018] In the control device of a working machine, the positional relationship information may represent relationship between (i) the first and second angular positions and (ii) an index value indicating whether the shortest distance is less than the predetermined value. In the calculation process, the control device may calculate the

index value as the positional relationship by applying the first and second angular positions acquired in the acquisition process to the positional relationship information.

[0019] In the control device of a working machine, the positional relationship information may include model information that simulates the working machine in a virtual coordinate system. The model information may include: vehicle body coordinate information representing position coordinates of various portions of the vehicle body with the vehicle body being placed at a predetermined reference position in the virtual coordinate system; a first relational equation representing relationship between (i) first coordinate information indicating position coordinates of various portions of the first member and (ii) the first angular position, with the vehicle body being placed at the reference position; and a second relational equation representing relationship between (I) second coordinate information indicating position coordinates of various portions of the second member and (II) the first and second angular positions, with the vehicle body being placed at the reference position. In the calculation process, the control device may apply the first angular position to the first relational equation to calculate the first coordinate information, apply the first and second angular positions to the second relational equation to calculate the second coordinate information, and calculate the shortest distance as the positional relationship based on the calculated first and second coordinate information and the vehicle body coordinate information.

[0020] To solve the above-described problem, a method of controlling a working machine is provided. A control device is applied to a working machine including: an attachment having: a first member rotatably connected to a vehicle body; and a second member rotatably connected to the first member; a drive unit having: a first drive device configured to drive the first member; and a second drive device configured to drive the second member; a first sensor configured to detect a first angular position indicating an angular position of the first member; and a second sensor configured to detect a second angular position indicating an angular position of the second member. The control device performs: an acquisition process in which the first and second angular positions are acquired while drive control is being performed to control the drive unit; and a coping process in which a measure is taken to avoid interference between the attachment and the vehicle body based on the first and second angular positions acquired in the acquisition process.

[0021] According to the above method, measures are taken to avoid interference between the attachment and the vehicle body based on the first and second angular positions. This can prevent the attachment from colliding with the vehicle body.

[0022] To solve the above-described problem, a control program for controlling a working machine is provided. A control device is applied to a working machine including: an attachment having: a first member rotatably

connected to a vehicle body; and a second member rotatably connected to the first member; a drive unit having: a first drive device configured to drive the first member; and a second drive device configured to drive the second member; a first sensor configured to detect a first angular position indicating an angular position of the first member; and a second sensor configured to detect a second angular position indicating an angular position of the second member. The control program causes the control device to perform: an acquisition process in which the first and second angular positions are acquired while drive control is being performed to control the drive unit; and a coping process in which a measure is taken to avoid interference between the attachment and the vehicle body based on the first and second angular positions acquired in the acquisition process.

[0023] The above-described program can cause the working machine to take measures to avoid interference between the attachment and the vehicle body based on the first and second angular positions. This can prevent the attachment from colliding with the vehicle body.

ADVANTAGEOUS EFFECTS

[0024] The above-described technical concept can prevent the attachment from colliding with the vehicle body.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025]

Fig. 1 is a side view schematically showing an excavator relating to a first embodiment.

Fig. 2 is a schematic plan view of the excavator.

Fig. 3 shows the electrical configuration and power transmission paths of the excavator.

Fig. 4 shows a virtual coordinate system.

Fig. 5 is a flowchart showing the steps of avoidance control relating to the first embodiment.

Fig. 6 schematically illustrates an avoidance map.

Fig. 7 is a flowchart showing the steps of avoidance control relating to a third embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

<First Embodiment>

[0026] The following now describes a first embodiment of a drive system of a working machine, a working machine, a control device of a working machine, a method of controlling a working machine, and a control program of a working machine, using a construction machine as an example. The drawings may show the constituent elements in an enlarged manner for the sake of better intelligibility. The ratios of the dimensions of the constituent elements may be different from those of the actual

components, and among the drawings.

<Overall Configuration>

[0027] As shown in Fig. 1, an excavator 10, which is a construction machine, has a lower body 13 and an upper body 14. The upper body 14 is located on the opposite side to the ground surface G with respect to the lower body 13. In the present embodiment, the term "upward direction" refers to the direction in which the upper body 14 is located when viewed from the lower body 13, and the term "downward direction" refers to the opposite direction. A specific one of the directions orthogonal to the upward direction is the frontward direction, and the opposite direction is the rearward direction. Furthermore, as shown in Fig. 2, the direction that is orthogonal to both of the upward and frontward directions faces the left and right directions, which are opposite to each other. The frontward and rearward directions may be collectively referred to as the X direction. The left and right directions may be collectively referred to as the Y direction. The upward and downward directions may be collectively referred to as the Z direction.

[0028] As shown in Fig. 1, the lower body 13 and the upper body 14 constitute a vehicle body 15. The lower body 13 has a rectangular parallelepiped shape, for example. The upper body 14 has a rectangular parallelepiped shape, for example. The interior of the upper body 14 is a hollow housing space. The housing space accommodates the various devices used to operate the excavator 10. Although not shown in the drawings, the upper body 14 has a cabin for accommodating an operator. The upper body 14 may be referred to as the upper revolving body.

[0029] As shown in Fig. 1, the excavator 10 includes a slewing bearing 18. The slewing bearing 18 is interposed between the lower body 13 and the upper body 14. In Fig. 1, the vertical width of the slewing bearing 18 is exaggeratedly large with respect to the Z direction. As shown in Fig. 2, the slewing bearing 18 has an annular inner ring 18A, an annular outer ring 18B, and a plurality of rolling elements. The rolling elements are not shown in Fig. 2. The outer diameter of the inner ring 18A is smaller than the inner diameter of the outer ring 18B. The central axis of the inner ring 18A is referred to as a slew axis 10J, which substantially coincides with the central axis of the outer ring 18B. The slew axis 10J extends upwards and downwards relative to the vehicle body 15, i.e., in the Z direction. As shown in Fig. 1, the slew axis 10J passes vertically through both the upper body 14 and the lower body 13. The rolling elements are located between the inner ring 18A and outer ring 18B. The rolling elements support the inner ring 18A and outer ring 18B such that they can rotate relative to each other. This enables the outer ring 18B to rotate about the slew axis 10J relative to the inner ring 18A. The inner ring 18A is fixed to the lower body 13. The outer ring 18B is fixed to the upper body 14. In other words, the upper body 14 is rotatable about the

slew axis 10J with respect to the lower body 13. Stated differently, the upper body 14 can rotate relative to the lower body 13.

[0030] As shown in Figs. 1 and 2, the lower body 13 includes a pair of traveling units 12. The traveling units 12 are provided at the left and right sides of the lower body 13. Both of the traveling units 12 are connected to the lower body 13. The traveling units 12 each include a traveling crawler, an operating mechanism for circulating the crawler, among other components. The crawler is shaped like an endless belt. The crawler is open on both the left and right sides. The lower surface of the crawler is in contact with the ground surface G. The excavator 10 travels as the crawler circulates. The traveling units 12 and lower body 13 may be collectively referred to as the lower traveling body.

[0031] As shown in Fig. 1, the excavator 10 includes a mounting wall 16. The mounting wall 16 is a constituent element of the excavator 10 that is not included in the vehicle body 15. The mounting wall 16 is located on the forward side with respect to the upper body 14. The mounting wall 16 is located at substantially the middle of the upper body 14 in the Y direction. The mounting wall 16 is fixed to the front surface of the upper body 14. In other words, the mounting wall 16 is attached to the vehicle body 15. The mounting wall 16 has a smaller rectangular parallelepiped shape than the upper body 14, for example. The interior of the mounting wall 16 is hollow.

<Attachment>

[0032] The excavator 10 includes a drive system. As shown in Fig. 1, the drive system has an attachment 20. The attachment 20 has a swing bracket 17, a boom 21, an arm 23, and a bucket 25.

[0033] As shown in Figs. 1 and 2, the swing bracket 17 is located on the forward side with respect to the upper body 14. The swing bracket 17 has a first swing wall 17A and a second swing wall 17B. The first swing wall 17A is located on the upper surface of the mounting wall 16. The first swing wall 17A is, for example, shaped like a disc. The first swing wall 17A is connected to the mounting wall 16. The first swing wall 17A can rotate, relative to the mounting wall 16, about a first axis 61J that extends upwards and downwards with respect to the vehicle body 15. The first axis 61J is substantially parallel to the slew axis 10J. The second swing wall 17B protrudes upward from the upper surface of the first swing wall 17A. The second swing wall 17B is, for example, shaped like a rectangular plate. Thus, the swing bracket 17 is rotatably connected to the vehicle body 15 via the mounting wall 16. The swing bracket 17 is equivalent to a first member.

[0034] As shown in Fig. 1, the boom 21 is located on the forward side with respect to the upper body 14. The boom 21 is shaped like an elongated plate or column. For example, the boom 21 is bent at an intermediate position in the longitudinal direction thereof. As shown in Fig. 2, a first end 21A of the boom 21 in the longitudinal direction is

aligned with the second swing wall 17B of the swing bracket 17 in a direction along a second axis 31J. The second axis 31J is a virtual axis that intersects the first axis 61J. Specifically, the second axis 31J is substantially orthogonal to the first axis 61J. The first end 21A of the boom 21 is rotatably connected to the second swing wall 17B. The boom 21 is equivalent to a second member.

[0035] As shown in Fig. 1, the arm 23 extends from a second end 21B of the boom 21 that is opposite the first end 21A. The arm 23 is shaped like an elongated plate or column. As shown in Fig. 2, a first end 23A of the arm 23 in the longitudinal direction is aligned with the second end 21B of the boom 21 in a direction along a third axis 41J. The third axis 41J is a virtual axis that is substantially parallel to the second axis 31J. The first end 23A of the arm 23 is rotatably connected to the second end 21B of the boom 21.

[0036] As shown in Fig. 1, the bucket 25 is located near a second end 23B of the arm 23 that is opposite the first end 23A. The bucket 25 has a bucket body 26, a plurality of teeth 27, and a bucket connecting wall 28. The bucket body 26 is shaped like a bucket. In other words, as shown in Fig. 2, the bucket body 26 has an opening 26A. The teeth 27 protrude from one of the edges of the rectangular opening of the bucket body 26. The bucket connecting wall 28 protrudes from a portion of the outer wall of the bucket body 26 that is located opposite the teeth 27 across the opening 26A. As shown in Fig. 2, the bucket connecting wall 28 is aligned with the second end 23B of the arm 23 in a direction along a fourth axis 51J. The fourth axis 51J is a virtual axis that is substantially parallel to both the second and third axes 31J and 41J. The bucket connecting wall 28 is rotatably connected to the second end 23B of the arm 23. The bucket 25 is equivalent to a working member.

<Drive Unit>

[0037] As shown in Fig. 3, the drive system of the excavator 10 includes a drive unit 30. The drive unit 30 is a set of devices for driving the attachment 20. The drive unit 30 includes a first drive device 61, a second drive device 31, a third drive device 41, and a fourth drive device 51. The drive unit 30 also includes a first inverter 65, a second inverter 35, a third inverter 45, a fourth inverter 55, and a battery 19. Although not shown, the first inverter 65, the second inverter 35, the third inverter 45, the fourth inverter 55, and the battery 19 are housed in the upper body 14.

[0038] As shown in Fig. 1, the first drive device 61 is housed in the mounting wall 16. As shown in Fig. 3, the first drive device 61 has a first electric motor 62 and a first speed reducer 63. The first electric motor 62 is a three-phase AC motor. The first electric motor 62 is electrically connected to the battery 19 via the first inverter 65. The first electric motor 62 has a housing 62A and an output shaft 62B that can rotate relative to the housing 62A. The housing 62A is attached to the mounting wall 16. The

output shaft 62B protrudes from the inside of the housing 62A to the outside. The output shaft 62B is shaped like a circular column. The output shaft 62B can rotate about its own central axis, which is referred to as the first axis 61J, with respect to the housing 62A. In other words, the output shaft 62B outputs torque about the first axis 61J. The output shaft 62B can rotate about the first axis 61J, 360 degrees in both the forward and reverse directions.

[0039] As shown in Fig. 3, the first speed reducer 63 has a housing 63A, a reduction mechanism 63B, and an output member 63C. The housing 63A is fixed to the housing 62A of the first electric motor 62. The reduction mechanism 63B is located inside the housing 63A. The reduction mechanism 63B receives torque input from the output shaft 62B of the first electric motor 62. The reduction mechanism 63B amplifies the torque from the first electric motor 62 at a predetermined ratio and outputs the amplified torque to the output member 63C. The reduction mechanism 63B may be, for example, an eccentric oscillating gear type or a planetary gear type. The output member 63C is cylindrical. The central axis of the output member 63C substantially coincides with the first axis 61J. The output member 63C is rotatable relative to the housing 63A. The output member 63C rotates about the first axis 61J in response to the rotation of the output shaft 62B of the first electric motor 62. The output member 63C is attached to the first swing wall 17A of the swing bracket 17. In other words, the output member 63C inputs torque about the first axis 61J to the swing bracket 17. The swing bracket 17 rotates about the first axis 61J in response to this torque. In other words, the first drive device 61 can be electrically driven by the first electric motor 62 to drive the swing bracket 17.

[0040] As shown in Fig. 2, the second drive device 31 is located between the second swing wall 17B of the swing bracket 17 and the first end 21A of the boom 21. The configuration of the second drive device 31 is basically the same as that of the first drive device 61, except for the dimensions, reduction ratio, output and other specific details. Therefore, the configuration of the second drive device 31 is only briefly described in the following.

[0041] As shown in Fig. 3, the second drive device 31 has a second electric motor 32 and a second speed reducer 33. The second electric motor 32 is electrically connected to the battery 19 via the second inverter 35. A housing 32A of the second electric motor 32 is mounted on the second swing wall 17B of the swing bracket 17. An output shaft 32B of the second electric motor 32 outputs torque about its own central axis, which is referred to as the second axis 31J. As shown in Fig. 2, the second axis 31J passes through both the second swing wall 17B of the swing bracket 17 and the first end 21A of the boom 21. An output member 33C of the second speed reducer 33 is attached to the first end 21A of the boom 21. As shown in Fig. 3, the output member 33C outputs torque about the second axis 31J. The boom 21 rotates about the second axis 31J in response to the torque from the output mem-

ber 63C. A housing 33A and a reduction mechanism 33B of the second speed reducer 33 have the same function as the housing 63A and reduction mechanism 63B of the first speed reducer 63. In other words, the second drive device 31 can be electrically driven by the second electric motor 32 to drive the boom 21.

[0042] As shown in Fig. 2, the third drive device 41 is located between the second end 21B of the boom 21 and the first end 23A of the arm 23. The configuration of the third drive device 41 is basically the same as that of the first drive device 61, except for the dimensions, reduction ratio, output and other specific details. Therefore, the configuration of the third drive device 41 is only briefly described in the following.

[0043] As shown in Fig. 3, the third drive device 41 has a third electric motor 42 and a third speed reducer 43. The third electric motor 42 is electrically connected to the battery 19 via the third inverter 45. A housing 42A of the third electric motor 42 is attached to the second end 21B of the boom 21. An output shaft 42B of the third electric motor 42 outputs torque about its own center axis, which is referred to as the third axis 41J. As shown in Fig. 2, the third axis 41J passes through both the second end 21B of the boom 21 and the first end 23A of the arm 23. An output member 43C of the third speed reducer 43 is attached to the first end 23A of the arm 23. As shown in Fig. 3, the output member 43C outputs torque about the third axis 41J. The arm 23 rotates about the third axis 41J in response to the torque from the output member 43C. A housing 43A and a reduction mechanism 43B of the third speed reducer 43 have the same function as the housing 63A and reduction mechanism 63B of the first speed reducer 63. In other words, the third drive device 41 can be electrically driven by the third electric motor 42 to drive the arm 23.

[0044] As shown in Fig. 2, the fourth drive device 51 is located between the second end 23B of the arm 23 and the bucket connecting wall 28 of the bucket 25. The configuration of the fourth drive device 51 is basically the same as that of the first drive device 61, except for the dimensions, reduction ratio, output and other specific details. Therefore, the configuration of the fourth drive device 51 is only briefly described in the following.

[0045] As shown in Fig. 3, the fourth drive device 51 has a fourth electric motor 52 and a fourth speed reducer 53. The fourth electric motor 52 is electrically connected to the battery 19 via the fourth inverter 55. A housing 52A of the fourth electric motor 52 is attached to the second end 23B of the arm 23. An output shaft 52B of the fourth electric motor 52 outputs torque about its own central axis, which is referred to as the fourth axis 51J. As shown in Fig. 2, the fourth axis 51J passes through both the second end 23B of the arm 23 and the bucket connecting wall 28. An output member 53C of the fourth speed reducer 53 is attached to the bucket connecting wall 28. As shown in Fig. 3, the output member 53C outputs torque about the fourth axis 51J. The bucket 25 rotates about the fourth axis 51J in response to the torque from

the output member 53C. A housing 53A and a reduction mechanism 53B of the fourth speed reducer 53 have the same function as the housing 63A and reduction mechanism 63B of the first speed reducer 63. In other words, the fourth drive device 51 can be electrically driven by the fourth electric motor 52 to drive the bucket 25.

[0046] As shown in Fig. 3, the excavator 10 includes a fifth drive device 71 and a fifth inverter 75. The fifth drive device 71 and fifth inverter 75 are housed in the upper body 14. The configuration of the fifth drive device 71 is basically the same as that of the first drive device 61, except for the dimensions, reduction ratio, output and other specific details. Therefore, the configuration of the fifth drive device 71 is only briefly described in the following.

[0047] As shown in Fig. 3, the fifth drive device 71 has a fifth electric motor 72 and a fifth speed reducer 73. The fifth electric motor 72 is electrically connected to the battery 19 via the fifth inverter 75. A housing 72A of the fifth electric motor 72 is attached to the upper body 14. An output shaft 72B of the fifth electric motor 72 outputs torque about its own central axis, which is referred to as a fifth axis 71J. An output member 73C of the fifth speed reducer 73 has a plurality of teeth. The teeth mesh with the teeth of the inner ring 18A of the slewing bearing 18. The output member 73C outputs torque about an axis coaxial with the fifth electric motor 72. This torque causes the upper body 14 to rotate with the housing 72A of the fifth electric motor 72, relative to the inner ring 18A and thus the lower body 13. In other words, the fifth drive device 71 causes the upper body 14 to rotate relative to the lower body 13. A housing 73A and a reduction mechanism 73B of the fifth speed reducer 73 have the same function as the housing 63A and reduction mechanism 63B of the first speed reducer 63.

<Sensors>

[0048] As shown in Fig. 3, the drive system of the excavator 10 has a first sensor 68, a second sensor 38, a third sensor 48, and a fourth sensor 58. The first sensor 68 detects first angle information 68S representing information about the angular position of the first electric motor 62. The angular position of the first electric motor 62 is strictly the angular position of the output shaft 62B of the first electric motor 62. For the other electric motors, their angular positions are similarly described without referring to their output shafts. The second sensor 38 detects second angle information 38S representing information about the angular position of the second electric motor 32. The third sensor 48 detects third angle information 48S representing information about the angular position of the third electric motor 42. The fourth sensor 58 detects fourth angle information 58S representing information about the angular position of the fourth electric motor 52. The angle information indicates an absolute angle. For example, the first angle information 68S indicates the angular position of the first electric

motor 62 in the range of "0 to 360 degrees" with a predetermined position being "0 degrees". The respective sensors repeatedly transmit the detected information to a control device 100, which will be described below.

[0049] Although not shown, the excavator 10 includes various other sensors necessary for operating the excavator 10 in addition to the above sensors. For example, the excavator 10 includes a sensor to detect the current value indicating the current flowing through each of the electric motors 32, 42, 52, 62 and 72, a sensor to detect the temperature of the battery 19, among other sensors. In addition, the excavator 10 includes an operating device 90 configured to be operated by the operator. The operating device 90 is located in the cabin. The operating device 90 repeatedly transmits an operation signal 90S in response to the operator's operation, to a control device 100, which will be described below.

<Control Device>

[0050] As shown in Fig. 3, the drive system of the excavator 10 has a control device 100. The control device 100 is a computer with a processing circuit. The processing circuit has a CPU 101 and a memory 102. The memory 102 includes three types of memories: a RAM, a ROM, and an electrically rewritable nonvolatile memory. In the present embodiment, these three types are collectively referred to as the memory 102. The memory 102 stores in advance various control programs 102A that describe the processes to be executed by the CPU 101. The memory 102 stores in advance various data 102B necessary for the CPU 101 to execute the control programs 102A. The processing circuit includes a communication circuit for wireless communication with an external device.

[0051] In addition, the CPU 101 can receive the first angle information 68S transmitted from the first sensor 68. The CPU 101 can receive the second angle information 38S transmitted from the second sensor 38. The CPU 101 can receive the third angle information 48S transmitted from the third sensor 48. The CPU 101 can receive the fourth angle information 58S transmitted from the fourth sensor 58. The CPU 101 can receive the operation signal 90S transmitted from the operating device 90.

[0052] The CPU 101 converts the first angle information 68S received from the first sensor 68 into the angular position of the swing bracket 17. Specifically, the CPU 101 calculates the actual angular position of the first electric motor 62, which is referred to as the actual angle, based on the first angle information 68S. Furthermore, the CPU 101 uses the actual angle of the first electric motor 62 and takes into consideration the reduction ratio of the first speed reducer 63 and other factors, to calculate the angular position of the swing bracket 17 from a predetermined first position. For example, the memory 102 knows in advance the actual angle of the first electric motor 62 observed when the swing bracket 17 is at the

first position. The CPU 101 sequentially stores in the memory 102 the history of the amount and direction of rotation of the swing bracket 17 from the first position as the first electric motor 62 rotates, and calculates the first angular position, which is the angular position of the swing bracket 17, based on the history. For example, the first position is an angular position of the swing bracket 17 where both of the main surfaces of the plate-shaped second swing wall 17B face the Y direction. As can be seen from the fact that the actual angle of the first electric motor 62 is converted into the first angular position, the first sensor 68 configured to detect the actual angle of the first electric motor 62 effectively detects the first angular position.

[0053] As in the case of the first electric motor 62, the CPU 101 converts the second angle information 38S received from the second sensor 38, which represents the actual angle of the second electric motor 32, into the second angular position pertaining to the boom 21. The second angular position is the angular position of the boom 21 from a predetermined second position. The second position is defined in the view of the excavator 10 as seen in the direction along the second axis 31J. For example, the second position is an angular position where both the first and second ends 21A and 21B of the boom 21 are positioned on a virtual straight line orthogonal to both the first and second axes 61J and 31J. When the second position is defined as in this example, the second end 21B of the boom 21 is positioned opposite the vehicle body 15 across the second axis 31J. The second position can also be regarded as the angular position of the boom 21 relative to the swing bracket 17. Like the first sensor 68, the second sensor 38, which is configured to detect the actual angle of the second electric motor 32, effectively detects the second angular position.

[0054] As in the cases of the above-described electric motors 32 and 62, the CPU 101 converts the third angle information 48S received from the third sensor 48, which represents the actual angle of the third electric motor 42, into a third angular position pertaining to the arm 23. The third angular position is the angular position of the arm 23 from a predetermined third position. The third position is defined in the view of the excavator 10 as seen in the direction along the third axis 41J. For example, the third position is an angular position where both the first and second ends 23A and 23B of the arm 23 are positioned on a virtual straight line passing through both the second and third axes 31J and 41J. When the third position is defined as in this example, the second end 23B of the arm 23 is positioned opposite the second axis 31J across the third axis 41J. The third angular position can also be regarded as the angular position of the arm 23 relative to boom 21. The third sensor 48, which detects the actual angle of the third electric motor 42, effectively detects the third angular position.

[0055] As in the cases of the above-described electric motors 32, 42 and 62, the CPU 101 converts the fourth

angle information 58S received from the fourth sensor 58, which represents the actual angle of the fourth electric motor 52, into a fourth angular position pertaining to the bucket 25. The fourth angular position is the angular position of the bucket 25 from a predetermined fourth position. The fourth position is defined in the view of the excavator 10 as seen in the direction along the fourth axis 51J. For example, the fourth position is an angular position where the teeth 27 of the bucket 25 are positioned on a virtual line passing through the third and fourth axes 41J and 51J. When the fourth position is defined as in this example, the teeth 27 of the bucket 25 are positioned opposite the third axis 41J across the fourth axis 51J. The fourth angular position can also be regarded as the angular position of the bucket 25 relative to the arm 23. The fourth sensor 58, which detects the actual angle of the fourth electric motor 52, effectively detects the fourth angular position.

[0056] The CPU 101 is designed to control the various components of the excavator 10, including the attachment 20. One of the components to be controlled is the drive unit 30. Specifically, the CPU 101 is designed to control the first electric motor 62 of the first drive device 61, the second electric motor 32 of the second drive device 31, the third electric motor 42 of the third drive device 41, the fourth electric motor 52 of the fourth drive unit 51, and the fifth electric motor 72 of the fifth drive unit 71. In controlling the first electric motor 62, the CPU 101 effectively controls the first inverter 65. Similarly, in controlling the second electric motor 32, the CPU 101 effectively controls the second inverter 35. Similarly, in controlling the third electric motor 42, the CPU 101 effectively controls the third inverter 45. Similarly, in controlling the fourth electric motor 52, the CPU 101 effectively controls the fourth inverter 55. Similarly, in controlling the fifth electric motor 72, the CPU 101 effectively controls the fifth inverter 75. In controlling the electric motors 32, 42, 52, 62 and 72, the CPU 101 refers to the angular positions of the members to be driven by the respective electric motors 32, 42, 52, 62 and 72. For example, in controlling the first electric motor 62, the CPU 101 refers to the first angular position pertaining to the swing bracket 17.

[0057] The following describes the various controls realized through execution of the control program 102A by the CPU 101. The CPU 101 performs drive control. In drive control, the CPU 101 controls the drive unit 30 to operate the attachment 20. Specifically, in performing drive control, the CPU 101 operates one or more of the electric motors 32, 42, 52, 62 and 72 included in the drive unit 30 in response to the operation signal 90S from the operating device 90. In other words, one or more of the electric motors 32, 42, 52, 62 and 72 are in operation while drive control is being performed. As mentioned above, the electric motors 32, 42, 52, 62 and 72 can rotate 360 degrees in both of the forward and reverse directions. Given such a wide range of motion, the attachment 20 may possibly reach the vicinity of the vehicle body 15 as the CPU 101 performs drive control. For example, the

double-dotted chain line 21X in Fig. 1 and the double-dotted chain line 21Y in Fig. 2 show an example case where the boom 21 is in the vicinity of the vehicle body 15.

[0058] The CPU 101 performs avoidance control while performing drive control. The avoidance control is designed to avoid interference between the attachment 20 and the vehicle body 15. As data necessary for the CPU 101 to perform avoidance control, the memory 102 stores in advance positional relationship information indicating the relationship between (i) the first angular position of the swing bracket 17 and the second angular position of the boom 21 and (ii) the positional relationship between the vehicle body 15 and the attachment 20. The positional relationship information stored in the memory 102 includes model information that simulates the excavator 10 in a virtual coordinate system 80Q. As shown in Fig. 4, the virtual coordinate system 80Q is a three-dimensional orthogonal Cartesian coordinate system defining locations surrounding the excavator 10. The X, Y, and Z axes of the virtual coordinate system 80Q respectively extend in the X, Y, and Z directions that define the front-back, left-right, up-down of the excavator 10. Fig. 4 only shows a two-dimensional plane formed by the X and Z axes, out of the three-dimensional virtual coordinate system 80Q.

[0059] The model information includes vehicle body coordinate information, a first relational equation, and a second relational equation. The vehicle body coordinate information indicates the position coordinates of various portions of the vehicle body 15 when the vehicle body 15 is placed at a reference position in the virtual coordinate system 80Q. Specifically, the vehicle body coordinate information is obtained by dividing the outer surface of the vehicle body 15 into a grid of a predetermined area and assigning a representative coordinate value to each cell of the grid. For example, the above-mentioned reference position is the position of the vehicle body 15 where the intersection of the slew axis 10J and the lower surface of the upper body 14 is located at the origin of the virtual coordinate system 80Q. However, the reference position is not limited to the position defined in this example and may be set in advance at an appropriate location. In other words, the orientation of the vehicle body 15 and the reference point for placing the vehicle body 15 in the virtual coordinate system 80Q can be determined as desired.

[0060] The first relational equation represents the relationship between (i) first coordinate information indicating the position coordinates of various portions of the swing bracket 17 and (ii) the first angular position of the swing bracket 17, with the vehicle body 15 being placed at the reference position. Note that the first angular position is variable and can take various values while drive control is performed. The first relational equation indicates the position coordinates of the swing bracket 17 corresponding to each value of the first angular position when the first angular position takes various values in association with execution of drive control. As with the vehicle body coordinate information, the first coordinate

information is obtained by dividing the outer surface of the swing bracket 17 into a grid of a predetermined area and assigning a representative coordinate value to each cell of the grid.

[0061] The second relational equation represents the relationship between (i) second coordinate information indicating the position coordinates of various portions of the boom 21 and (ii) the first angular position of the swing bracket 17 and the second angular position of the boom 21, with the vehicle body 15 being placed at the reference position. In other words, the second relational equation indicates the position coordinates of the boom 21 corresponding to each combination of the values of the first and second angular positions when the first and second angular positions take various values. Like the first coordinate information, the second coordinate information is obtained by dividing the outer surface of the boom 21 into a grid of a predetermined area and assigning a representative coordinate value to each cell of the grid.

<Sequence of Steps for Avoidance Control>

[0062] When the CPU 101 starts drive control in response to the operation signal 90S, it starts avoidance control in parallel. If the CPU 101 terminates the drive control in the middle of the execution of the avoidance control, it simultaneously terminates the avoidance control. In other words, the CPU 101 executing avoidance control means that the attachment 20 is in motion.

[0063] As shown in Fig. 5, in the avoidance control, the CPU 101 first performs the step S10. In the step S10, the CPU 101 performs an acquisition process. In the step S10, the CPU 101 acquires the angle information of the swing bracket 17 and boom 21. Specifically, the CPU 101 acquires the most recent value of the first angular position of the swing bracket 17 and the most recent value of the second angular position of the boom 21. Upon acquiring the first and second angular positions, the CPU 101 completes the process of the step S10. The CPU 101 then proceeds to the step S20.

[0064] In the step S20, the CPU 101 performs a calculation process. In the step S20, the CPU 101 applies the first and second angular positions acquired in the acquisition process to the positional relationship information stored in the memory 102, thereby calculating the positional relationship between the vehicle body 15 and the attachment 20. Specifically, the CPU 101 applies the value of the first angular position to the first relational equation of the model information included in the positional relation information, thereby calculating the first coordinate information indicating the position information of various portions of the swing bracket 17. In addition, the CPU 101 applies the values of the first and second angular positions to the second relational equation of the model information included in the positional relation information, thereby calculating the second coordinate information indicating the position coordinates of various portions of the boom 21. The CPU 101 then calculates the

positional relationship between the attachment 20 and the vehicle body 15, specifically, the shortest distance between them, based on the calculated first and second coordinate information and the vehicle body coordinate information indicating the position coordinates of various portions of the vehicle body 15. Here, the attachment 20 is limited to the swing bracket 17 and the boom 21. In other words, the shortest distance is calculated by the CPU 101 between the vehicle body 15 and the nearest portion from among the portions of the outer surfaces of the swing bracket 17 and boom 12. Upon calculating the shortest distance, the CPU 101 terminates the process in the step S20. The CPU 101 then proceeds to the step S30.

[0065] In the step S30, the CPU 101 determines whether the shortest distance between the attachment 20 and the vehicle body 15 is less than a predetermined value. For example, the predetermined value indicates a distance that is determined in advance by experiment or simulation and that can prevent interference between the attachment 20 and the vehicle body 15 even if the electric motors are suspended at a slightly erroneous timing. The predetermined value is, for example, several tens of centimeters. If the shortest distance is determined to be equal to or greater than the predetermined value (step S30: NO), the CPU 101 proceeds to the step S10 and performs the processes in the steps S10 to S30 again. On the other hand, if the shortest distance is determined to be less than the predetermined value (step S30: YES), the CPU 101 proceeds to the step S40.

[0066] In the step S40, the CPU 101 performs a coping process. Since the shortest distance between the attachment 20 and the vehicle body 15 is already determined to be less than the predetermined value in the step S30, the CPU 101 takes measures to avoid interference between the attachment 20 and the vehicle body 15 in the coping process. In the present embodiment, the CPU 101 controls the first drive device 61 of the drive unit 30 to stop the motion of the swing bracket 17 and also controls the second drive device 31 of the drive unit 30 to stop the motion of the boom 21. When the swing bracket 17 and boom 21 stop moving, the CPU 101 completes the process of the step S40.

<How First Embodiment Works>

[0067] The following now describes how the attachment 20 shown in Figs. 1 and 2 moves. In the attachment 20, upon rotation of the output shaft 62B of the first electric motor 62, the output member 63C of the first speed reducer 63 rotates along with the output shaft 62B. The rotation speed of the output member 63C is reduced at a predetermined ratio relative to the rotation speed of the output shaft 62B of the first electric motor 62. In other words, the first speed reducer 63 amplifies the torque output by the output shaft 62B of the first electric motor 62 and outputs the amplified torque. The rotation of the output member 63C causes the first and second

swing walls 17A and 17B of the swing bracket 17 to rotate. The boom 21, which is connected to the second swing wall 17B via the second drive device 31, then rotates. Through the above series of power transmissions, the boom 21 swings left and right about the first axis 61J.

[0068] Furthermore, in the attachment 20, the rotation of the output shaft 32B of the second electric motor 32 causes the output member 33C of the second speed reducer 33 to rotate along with the output shaft 32B. The rotation speed of the output member 33C is reduced at a predetermined ratio relative to the rotation speed of the output shaft 32B of the second electric motor 32. In other words, the second speed reducer 33 amplifies the torque output by the output shaft 32B of the second electric motor 32 and outputs the amplified torque. As the output member 33C rotates, the boom 21 rotates. Through the above series of power transmissions, the boom 21 rotates about the second axis 31J.

<Advantageous Effects of First Embodiment>

[0069] (1-1) When the swing bracket 17 and the boom 21 are driven by the electric motors 62 and 32 as described in relation with the present embodiment, the swing bracket 17 and the boom 21 can have a wider range of motion than when the swing bracket 17 and the boom 21 are driven hydraulically. This creates a problem that the swing bracket 17 and the boom 21 tend to interfere with the vehicle body 15. In particular, if the rotation of the swing bracket 17 concurrently occurs with the rotation of the boom 21, they are more likely to interfere with the vehicle body 15.

[0070] To address this issue, the present embodiment is configured to calculate the shortest distance between the attachment 20 and the vehicle body 15 based on the first coordinate information indicating the position information of the swing bracket 17, the second coordinate information indicating the position coordinates of the boom 21, and the vehicle body coordinate information indicating the position coordinates of the vehicle body 15. If the calculated shortest distance is determined to be less than the predetermined value, measures are taken to avoid interference between the swing bracket 17 and boom 21, and the vehicle body 15. This prevents the swing bracket 17 and boom 21 from colliding with the vehicle body 15.

[0071] (1-2) The step S30 of the avoidance control determines whether the shortest distance from the swing bracket 17 and boom 21 to the vehicle body 15 is less than the predetermined value. The swing bracket 17 and boom 21 of the attachment 20 are positioned nearer the vehicle body 15 than are the arm 23 and bucket 25, and are therefore more likely to collide with the vehicle body 15. For this reason, by taking measures to avoid interference between the attachment 20 and the vehicle body 15 when the shortest distance is less than the predetermined value, collision between the attachment 20 and the vehicle body 15 can be reliably prevented.

[0072] (1-3) In the step S40 of the avoidance control, the CPU 101 controls the drive devices 31 and 61 to stop the motion of the swing bracket 17 and boom 21. Accordingly, this measure for avoiding interference between the attachment 20 and the vehicle body 15 ensures that a collision of the attachment 20 with the vehicle body 15 is forcibly prevented, compared to a rather simple measure where an alarm is issued.

[0073] (1-4) According to the present embodiment, the positional relationship information stored in the memory 102 includes the model information that simulates the excavator 10 in the virtual coordinate system 80Q. The CPU 101 applies the first angular position of the swing bracket 17 to the first relational equation included in the model information, thereby calculating the first coordinate information indicating the position coordinates of various portions of the swing bracket 17. Furthermore, the CPU 101 applies the first angular position and the second angular position of the boom 21 to the second relational equation included in the model information, thereby calculating the second coordinate information indicating the position coordinates of various portions of the boom 21. Furthermore, the CPU 101 uses the calculated first and second coordinate information and the vehicle body coordinate information indicating the position coordinates of various portions of the vehicle body 15, to calculate the shortest distance between the attachment 20 and the vehicle body 15. In this way, the shortest distance can be calculated accurately and easily.

<Second Embodiment>

[0074] The following now describes a second embodiment of a drive system of a working machine, a working machine, a control device of a working machine, a method of controlling a working machine, and a control program of a working machine. The second embodiment is different from the first embodiment in terms of what is included in the model information and accordingly what is performed in avoidance control. Except for these points, the second embodiment is basically the same as the first embodiment. In the following description of the second embodiment, redundant description of the same features as in the first embodiment may be omitted or simplified to focus on the differences from the first embodiment.

[0075] In the second embodiment, the model information stored by the memory 102 includes a third relational equation and a fourth relational equation, in addition to the vehicle body coordinate information, the first relational equation, and the second relational equation. The vehicle body coordinate information, the first relational equation, and the second relational equation are as described in the first embodiment. The third relational equation represents the relationship between (i) third coordinate information, which indicates the position coordinates of various portions of the arm 23, and (ii) the first, second, and third angular positions. The third angu-

lar position is the angular position of the arm 23, as already explained. The third relational equation is similar to the first and second relational equations, but is defined based on the relationship between the outer surface of the arm 23 and combinations of the three angular positions. The fourth relational equation represents the relationship between (i) the fourth coordinate information, which indicates the position coordinates of various portions of the bucket 25, and (ii) the first, second, third, and fourth angular positions. The fourth angular position is the angular position of the bucket 25, as already explained. The fourth relational equation is similar to the first and other relational equations, but is defined based on the relationship between the outer surface of the bucket 25 and combinations of the four angular positions. The model information described above constitutes information indicating the relationship between (i) the first, second, third, and fourth angular positions and (ii) the positional relationship between the vehicle body 15 and the attachment 20.

[0076] In the avoidance control relating to the present embodiment, the CPU 101 performs the following processes. In the step S10 shown in Fig. 5, the CPU 101 acquires the first angular position of the swing bracket 17, the second angular position of the boom 21, the third angular position of the arm 23, and the fourth angular position of the bucket 25. In the next step S20, the CPU 101 applies the first, second, third, and fourth angular positions acquired in the acquisition process to the positional relationship information stored in the memory 102. This allows the CPU 101 to calculate the positional relationship between the vehicle body 15 and the attachment 20. Specifically, the CPU 101 applies the first angular position to the first relational equation of the model information to calculate the first coordinate information indicating the position information of various portions of the swing bracket 17. The CPU 101 applies the first and second angular positions to the second relational equation of the model information to calculate the second coordinate information indicating the position coordinates of various portions of the boom 21. The CPU 101 applies the first, second and third angular positions to the third relational equation of the model information to calculate the third coordinate information indicating the position coordinates of various portions of the arm 23. The CPU 101 applies the first, second, third and fourth angular positions to the fourth relational equation of the model information to calculate the fourth coordinate information indicating the position coordinates of various portions of the bucket 25. The CPU 101 then calculates the positional relationship or the shortest distance between the attachment 20 and the vehicle body 15 based on the calculated first, second, third, and fourth coordinate information and the vehicle body coordinate information indicating the position coordinates of various portions of the vehicle body 15. In this case, the shortest distance is determined between the vehicle body 15 and the portion nearest the vehicle body 15 among the var-

ious portions of the outer surfaces of the swing bracket 17, boom 21, arm 23, and bucket 25. Upon calculation of the shortest distance, the CPU 101 proceeds to the step S30. The CPU 101 determines whether the shortest distance between the attachment 20 and the vehicle body 15 is less than a predetermined value. If the shortest distance is determined to be less than the predetermined value (step S30: YES), the CPU 101 proceeds to the step S40.

[0077] In the step S40, the CPU 101 takes measures to avoid interference between the attachment 20 and the vehicle body 15. In the present embodiment, the CPU 101 controls the first drive device 61 to stop the motion of the swing bracket 17 and controls the second drive device 31 to stop the motion of the boom 21. Furthermore, the CPU 101 controls the third drive device 41 to stop the motion of the arm 23 and controls the fourth drive device 51 to stop the motion of the bucket 25. When the swing bracket 17, boom 21, arm 23, and bucket 25 stop moving, the CPU 101 completes the process of the step S40.

<Advantageous Effects of Second Embodiment>

[0078] The configuration of the present embodiment produces the same advantageous effects as described in (1-1) to (1-4). Furthermore, the configuration of the present embodiment also produces the following advantageous effects.

[0079] (2-1) In the present embodiment, the shortest distance between the attachment 20 and the vehicle body 15 is calculated based on the third coordinate information indicating the position coordinates of the arm 23 and the fourth coordinate information indicating the position coordinates of the bucket 25, in addition to the first coordinate information, second coordinate information and vehicle body coordinate information. If the calculated shortest distance is determined to be less than a predetermined value, measures are taken to avoid interference between the attachment 20 and the vehicle body 15. In other words, in taking measures to avoid the interference, not only the positions of the swing bracket 17 and boom 21, but also the positions of the arm 23 and bucket 25 are considered. This more reliably prevents the attachment 20 from colliding with the vehicle body 15.

<Third Embodiment>

[0080] The following now describes a third embodiment of a drive system of a working machine, a working machine, a control device of a working machine, a method of controlling a working machine, and a control program of a working machine. In the present embodiment, information that differs in nature from the model information is employed as the positional relationship information. In conjunction with this, the third embodiment is different from the first embodiment in terms of what processes are performed in avoidance control. Except

for these points, the third embodiment is basically the same as the first embodiment. In the following description of the third embodiment, redundant description of the same features as in the first embodiment may be omitted or simplified to focus on the differences from the first embodiment.

[0081] In the present embodiment, the positional relationship information stored by the memory 102 is an avoidance map 110. As shown in Fig. 6, the avoidance map 110 is a graph showing the relationship between the first angular position, which is the angular position of the swing bracket 17, the second angular position, which is the angular position of the boom 21, and an avoidance index value. Specifically, the avoidance map 110 defines an avoidance index value for each combination of the first and second angular positions. The avoidance index value represents whether the shortest distance between the attachment 20 and the vehicle body 15 is less than a predetermined value. The avoidance index value assumes either a first value indicating that the shortest distance is less than the predetermined value or a second value indicating that the shortest distance is equal to or greater than the predetermined value. In the avoidance map 110, either the first or second value is set for each combination of the first and second angular positions. For example, the avoidance map 110 shown in Fig. 6 indicates that the first angular position is "0°" when the swing bracket 17 is at the first position or both of the main surfaces of the second swing wall 17B of the swing bracket 17 face the Y direction. In the avoidance map 110, the second angular position is "0°" when the boom 21 is at the second position or both the first end 21A and the second end 21B of the boom 21 are on the virtual straight line orthogonal to both the first and second axes 61J and 31J. In the avoidance map 110, the first value is set for the combinations in the domain without dots and the second value is set for the combinations in the domain with dots. The domains where the first and second values are respectively set in the avoidance map 110 can vary depending on the shape of the vehicle body 15 and other factors. The avoidance map 110 is generated based on simulations using a model that replicates the excavator 10. The simulations are performed for the attachment 20, more specifically, the swing bracket 17 and boom 21. In other words, the avoidance map 110 is for the swing bracket 17 and boom 21 in the present embodiment.

[0082] In the present embodiment, the CPU 101 performs the following processes in the avoidance control. As shown in Fig. 7, in the initial step S110, the CPU 101 performs an acquisition process, in which it acquires the first angular position of the swing bracket 17 and the second angular position of the boom 21. The details of the step S110 are the same as those of the step S10 relating to the first embodiment.

[0083] After the step S110, the CPU 101 performs a calculation process in the step S120. In the step S120, the CPU 101 applies the first and second angular positions acquired in the step S110 to the avoidance map 110,

to calculate the positional relationship, specifically, an avoidance index value corresponding to the first and second angular positions.

[0084] After the step S120, the CPU 101 determines in the step S130 whether the shortest distance between the attachment 20 and the vehicle body 15 is less than the predetermined value. If the avoidance index value calculated in the step S120 is the second value, the CPU 101 determines that the shortest distance is equal to or greater than the predetermined value (step S130: NO). In this case, the CPU 101 returns to the step S110. On the other hand, if the avoidance index value calculated in the step S120 is the first value, the CPU 101 determines that the shortest distance is less than the predetermined value (step S130: YES). In this case, the CPU 101 proceeds to the step S140. The details of the process performed in the step S140 are the same as those in the step S40 relating to the first embodiment.

<Advantageous Effects of Third Embodiment>

[0085] The third embodiment produces the same advantageous effect as described in (1-2) and (1-3). Furthermore, the configuration of the third embodiment also has the following advantageous effects.

[0086] (3-1) Like the first embodiment, the third embodiment can prevent the swing bracket 17 and boom 21 from colliding with the vehicle body 15. To realize this goal, the third embodiment provides in advance the avoidance map 110 where the avoidance index value is defined for each combination of the first and second angular positions. The avoidance map 110 can be used simply by applying the first and second angular positions to the avoidance map 110. In this way, the avoidance map 110 can immediately tell whether the shortest distance between the attachment 20 and the vehicle body 15 is less than the predetermined value. This eliminates the need for complex processing from the calculation of the shortest distance, thereby reducing the processing load on the CPU 101.

<Modification Examples>

[0087] The above embodiments can be modified as described below. The above embodiments and the following modification examples can be implemented in combination to the extent where they are technically consistent to each other.

[0088] The positional relationship information stored by the memory 102 is not limited to the examples described in the above embodiments. The positional relationship information is only required to indicate the relationship between (i) the angular positions of the members constituting the attachment 20 and (ii) the positional relationship between the vehicle body 15 and the attachment 20. For example, the positional relationship information may be a table in which index values are defined in advance for respective combinations of the first, second,

third, and fourth angular positions. In this case, the index values can be set in view of not only the swing bracket 17 and boom 21 but also the arm 23 and bucket 25, among the members constituting the attachment 20.

[0089] The details of the acquisition and calculation processes performed in the avoidance control are not limited to the examples described in the above embodiments. The acquisition process is only required to produce the angular positions needed for the calculation process and the like. The calculation process is only required to calculate the positional relationship between the vehicle body 15 and the attachment 20. For example, in addition to the first angular position of the swing bracket 17 and the second angular position of the boom 21, the acquisition process may acquire either the third angular position of the arm 23 or the fourth angular position of the bucket 25. The calculation process may then calculate the positional relationship between the vehicle body 15 and the attachment 20 based on the relationship between these three angular positions and the orientation of the attachment 20. In addition to the first to fourth angular positions, the acquisition and calculation processes may also use the angular positions of fifth or higher members rotatably connected to the working member.

[0090] The information representing the positional relationship calculated in the calculation process is not limited to the shortest distance or the avoidance index value, but is only required to be able to suggest the shortest distance between the attachment 20 and the vehicle body 15. The acquisition and calculation processes, as well as the positional relationship information, are only required to be configured such that appropriate information can be calculated.

[0091] The details of the coping process in the avoidance control are not limited to the examples described in the above embodiments. The coping process is only required to take measures to avoid interference between the attachment 20 and the vehicle body 15 based on the orientation of the attachment 20. For example, in the first embodiment, the CPU 101 may control the drive unit 30 such that either the swing bracket 17 or the boom 21 stops moving. In addition to controlling the drive unit 30 such that the swing bracket 17 and boom 21 stop moving, the CPU 101 may also control the drive unit 30 such that at least one of the arm 23 or the bucket 25 stops moving. Similarly, the second embodiment may be modified such that the CPU 101 may control one or more of the swing bracket 17, the boom 21, the arm 23, and the bucket 25 such that they stop moving, instead of controlling all such that they stop moving. As long as the interference between the attachment 20 and the vehicle body 15 can be avoided, the drive unit 30 can be controlled in any manner in the coping process. For example, the CPU 101 may gradually decrease the moving speed of the attachment 20. Furthermore, the coping process is configured to prevent by itself the interference between the attachment 20 and the vehicle body 15, but can be configured in any other manner. For example, the coping process may

include alerting the operator to the possibility of interference between the attachment 20 and the vehicle body 15. Specifically, the CPU 101 may use text, sound, a lamp and the like to notify the operator that there is a possibility of interference between the attachment 20 and the vehicle body 15. As described, the coping process is only required to take any measures leading to avoidance of interference between the attachment 20 and the vehicle body 15.

[0092] The predetermined value based on which whether the shortest distance between the attachment 20 and the vehicle body 15 is allowable may depend on the portions of the vehicle body 15. For example, a first predetermined value is set for the upper body 14, a second predetermined value is set for the lower traveling body constituted by the traveling units 12 and lower body 13, and the first and second predetermined values may be set different from each other.

[0093] In the above embodiments, the coping process is performed if the shortest distance between the attachment 20 and the vehicle body 15 is less than the predetermined value. However, the coping process may be performed under any other conditions. Whether there is a need to perform the coping process may be determined as appropriate based on the information acquired in the acquisition process or the like. The coping process may be performed as needed.

[0094] The first drive device 61 may be configured in any other manner than in the above embodiments. The first drive device 61 may be only required to include an electric motor and to cause the swing bracket 17 to rotate. For example, the first speed reducer 63 may be eliminated from the first drive device 61. The output shaft 62B of the first electric motor 62 may then be treated as an output member of the first drive unit 61. Furthermore, the first drive device 61 may be configured in any other manner than outputting torque coaxially with the output shaft of the electric motor to outside. For example, the first drive device 61 may be configured to convert the rotational motion of the first electric motor 62 into a linear motion and output the linear motion. The manner in which the swing bracket 17 is connected may be modified such that the linear motion can cause the swing bracket 17 to rotate about a specific axis of rotation. The first drive device 61 may include a ball screw mechanism to convert the rotational motion into the linear motion, for example. Thus, the mechanism for driving the swing bracket 17 is not limited to the examples described in the above embodiments. Furthermore, depending on the changes made to the mechanism configured to drive the swing bracket 17, the connection between the swing bracket 17 and the vehicle body 15, and the configuration of the swing bracket 17 itself may be changed from those described in the above illustrative embodiment. The swing bracket 17 may be connected directly to the vehicle body 15. The swing bracket 17 is only required to be rotatably connected to the vehicle body 15 such that it can rotate about an axis extending upwards and downwards

with respect to the vehicle body 15.

[0095] Similar to the above modification examples regarding the first drive device 61, the configuration of the second drive device 31 is not limited to the examples described in the above embodiments. The second drive device 31 is only required to include an electric motor and to be configured to cause the boom 21 to rotate. The second speed reducer 33 may be eliminated from the second drive device 31, or a mechanism may be provided to convert the rotational motion of the second electric motor 32 into linear motion.

[0096] Similar to the above modification examples regarding the first drive device 61, the configuration of the third drive device 41 is not limited to the examples described in the above embodiments. The third drive device 41 may be only required to include an electric motor and to be configured to cause the arm 23 to rotate. The third speed reducer 43 may be eliminated from the third drive device 41, or a mechanism may be provided to convert the rotational motion of the third electric motor 42 into linear motion.

[0097] Similar to the above modification examples regarding the first drive device 61, the configuration of the fourth drive device 51 is not limited to the examples described in the above embodiments. The fourth drive device 51 is only required to include an electric motor and to be configured to cause the bucket 25 to rotate. The fourth speed reducer 53 may be eliminated from the fourth drive device 51, or a mechanism may be provided to convert the rotational motion of the fourth electric motor 52 into linear motion.

[0098] Similar to the above modification examples regarding the first drive device 61, the configuration of the fifth drive device 71 is not limited to the examples described in the above embodiments. The fifth drive device 71 is only required to include an electric motor and to be configured to cause the inner ring 18A of the slewing bearing 18 to rotate. The fifth speed reducer 73 may be eliminated from the fifth drive device 71, or a mechanism may be provided to convert the rotational motion of the fifth electric motor 72 into linear motion.

[0099] The configuration of the attachment 20 is not limited to the examples described in the above embodiments. The attachment 20 is only required to include a first member rotatably connected to the vehicle body 15 and a second member rotatably connected to the first member. The attachment 20 may consist of only two members, the first and second members, or may be made up of five or more members connected together.

[0100] The first and second members are not limited to the examples described in the above embodiments. For example, the first member may be the boom 21, and the second member may be the arm 23. In this case, the swing bracket 17 may be eliminated. In other words, the first member does not have to be configured to rotate about the first axis 61J, which extends upwards and downwards relative to the vehicle body 15, relative to the vehicle body 15.

[0101] The working member is not limited to the bucket 25. Appropriate devices, mechanisms, instruments and the like may be employed as the working member depending on the work. If the working member is not required to have rotatability, the fourth drive device 51 can be eliminated and the working member can be directly connected to the arm 23.

[0102] The arm 23 and bucket 25 are not essential elements. The bucket 25 may be eliminated. If the bucket 25 is eliminated, the fourth drive device 51 may be eliminated accordingly. The arm 23 can be eliminated, and the bucket 25 can be connected to the boom 21 without the arm 23. If the arm 23 is eliminated, the third drive device 41 may be eliminated accordingly.

[0103] The configuration of the mounting wall 16 is not limited to the examples described in the above embodiments. For example, the mounting wall 16 may have a different shape than a rectangular parallelepiped shape. The mounting wall 16 is only required to connect the swing bracket 17 to the vehicle body 15. The mounting wall 16 can be eliminated if the swing bracket 17 can be connected to the vehicle body 15 without the use of a wall categorized as the mounting wall 16. Stated differently, the mounting wall 16 is not an essential component.

- The configuration of the upper body 14 is not limited to the example of the above embodiment. For example, the cabin may be eliminated from the upper body 14. The upper body 14 may have other shape than a rectangular parallelepiped shape. The upper body 14 can be configured in any manner as long as it can provide for the required functions, for example, housing the various devices.

[0104] In conjunction with eliminating the cabin from the upper body 14 as in the above modification example, the operating device 90 may be eliminated from the upper body 14. Along with this, the operation signal 90S transmitted to the drive unit 30 may be transmitted via wireless communication from a device external to the vehicle body 15. In other words, the source device of the operation signal 90S is not limited to those provided on the vehicle body 15.

[0105] The overall configuration of the vehicle body 15 and thus the excavator 10 is not limited to the example of the above embodiments. For example, the vehicle body 15 may have a different overall shape than in the above illustrative embodiments, in accordance with the different shape of the upper body 14 described in the above modification example. The excavator 10 is only required to be configured as a whole to realize required work, for example, excavation.

[0106] The working machine is not limited to the excavator 10. The working machine may be any construction machine other than the excavator 10. Furthermore, the working machine is not limited to a construction machine. Other than a construction machine, examples of the working machine include machines used in for-

estry, crushed-stone production, industrial waste treatment, and agriculture.

[0107] The processing circuit of the control device 100 is acceptable as long as it is configured in any one of the following manners (a) to (c).

(a) The processing circuit has one or more processors that perform various processes according to a computer program. The processors include the CPU 101 and the memory 102 such as a RAM or a ROM. The memory 102 stores program codes or instructions configured to cause the CPU 101 to perform processes. The memory 102, or a computer-readable medium, encompasses any kind of available media accessible by a general-purpose or dedicated computer.

(b) The processing circuit includes one or more dedicated hardware circuits that perform various processes. The dedicated hardware circuits can be, for example, application-specific integrated circuits, i.e., ASICs or FPGAs.

(c) The processing circuit includes a processor that performs part of the various processes according to a computer program and a dedicated hardware circuit that performs the rest of the various processes.

[0108] The foregoing embodiments describe a plurality of physically separate constituent parts. They may be combined into a single part, and any one of them may be divided into a plurality of physically separate constituent parts. Irrespective of whether or not the constituent parts are integrated, they are acceptable as long as they are configured to solve the problems.

[0109] According to the foregoing embodiments, a plurality of functions are distributively provided. Some or all of the functions may be integrated. Any one of the functions may be partly or entirely segmented into a plurality of functions, which are distributively provided. Irrespective of whether the functions are integrated or distributed, they are acceptable as long as they are configured to attain the object of the invention.

Claims

1. A drive system of a working machine, the drive system comprising:

an attachment having: a first member rotatably connected to a vehicle body of the working machine; and a second member rotatably connected to the first member;

a drive unit having: a first drive device configured to drive the first member; and a second drive device configured to drive the second member;

a first sensor configured to detect a first angular position indicating an angular position of the first member;

a second sensor configured to detect a second angular position indicating an angular position of the second member; and

a control device configured to perform drive control to control the drive unit, wherein the control device performs:

an acquisition process in which the first and second angular positions are acquired while the drive control is being performed; and

a coping process in which a measure is taken to avoid interference between the attachment and the vehicle body based on the first and second angular positions acquired in the acquisition process.

2. The drive system of claim 1, wherein, in the coping process, the control device controls the first drive device such that the first member stops moving and controls the second drive device such that the second member stops moving.

3. The drive system of claim 1 or 2, wherein the control device:

stores in advance positional relationship information indicating relationship between (i) the first and second angular positions and (ii) positional relationship between the vehicle body and the attachment;

performs a calculation process in which the positional relationship is calculated by applying the first and second angular positions acquired in the acquisition process to the positional relationship information; and

performs the coping process if the positional relationship calculated in the calculation process indicates that a shortest distance between the attachment and the vehicle body is less than a predetermined value.

4. The drive system of claim 3,

wherein the positional relationship information represents relationship between (i) the first and second angular positions and (ii) an index value indicating whether the shortest distance is less than the predetermined value, and

wherein, in the calculation process, the control device calculates the index value as the positional relationship by applying the first and second angular positions acquired in the acquisition process to the positional relationship information.

5. The drive system of claim 3,

wherein the positional relationship information includes model information that simulates the working machine in a virtual coordinate system, wherein the model information includes:

5 vehicle body coordinate information representing position coordinates of various portions of the vehicle body with the vehicle body being placed at a predetermined reference position in the virtual coordinate system; 10
a first relational equation representing relationship between (i) first coordinate information indicating position coordinates of various portions of the first member and 15 (ii) the first angular position, with the vehicle body being placed at the reference position; and
a second relational equation representing relationship between (I) second coordinate 20 information indicating position coordinates of various portions of the second member and (II) the first and second angular positions, with the vehicle body being placed at the reference position, and 25
wherein, in the calculation process, the control device applies the first angular position to the first relational equation to calculate the first coordinate information, applies the first and second angular positions to the 30 second relational equation to calculate the second coordinate information, and calculates the shortest distance as the positional relationship based on the calculated first and second coordinate information and 35 the vehicle body coordinate information.

6. The drive system of claim 1 to 5,

wherein the first drive device is driven by a first 40 electric motor, and
wherein the second drive device is driven by a second electric motor.

7. The drive system of claim 1 to 6, 45

wherein the first member is a swing bracket configured to rotate about a first axis extending upwards and downward relative to the vehicle body, and 50
wherein the second member is a boom configured to rotate about a second axis intersecting the first axis.

8. The drive system of claim 7, 55
wherein the attachment includes:

an arm rotatably connected to the boom, the arm

being configured to rotate about a third axis parallel to the second axis; and
a working member rotatably connected to the arm, the working member being configured to rotate about a fourth axis parallel to the second axis,

wherein the drive unit includes:

a third drive device configured to be driven by a third electric motor, the third drive device being configured to drive the arm; and
a fourth drive device configured to be driven by a fourth electric motor, the fourth drive device being configured to drive the working member, 30
wherein the drive system comprises:

a third sensor configured to detect a third angular position indicating an angular position of the arm; and
a fourth sensor configured to detect a fourth angular position indicating an angular position of the working member, and
wherein the control device:

stores in advance positional relationship information indicating relationship between (i) the first, second, third and fourth angular positions and (ii) positional relationship between the vehicle body and the attachment;
in the acquisition process, acquires the first, second, third and fourth angular positions;
performs a calculation process in which the positional relationship is calculated by applying the first, second, third and fourth angular positions acquired in the acquisition process to the positional relationship information; and
performs the coping process if the positional relationship calculated in the calculation process indicates that a distance between the attachment and the vehicle body is less than a predetermined value.

9. A working machine comprising:

a vehicle body;
an attachment having: a first member rotatably connected to the vehicle body; and a second member rotatably connected to the first member;
a drive unit having: a first drive device configured

to drive the first member; and a second drive device configured to drive the second member; a first sensor configured to detect a first angular position indicating an angular position of the first member; 5
a second sensor configured to detect a second angular position indicating an angular position of the second member; and
a control device configured to perform drive control to control the drive unit, 10
wherein the control device performs:

an acquisition process in which the first and second angular positions are acquired while the drive control is being performed; 15
and
a coping process in which a measure is taken to avoid interference between the attachment and the vehicle body based on the first and second angular positions 20
acquired in the acquisition process.

10. A control device of a working machine, wherein the control device is applied to a working machine including: 25

an attachment having: a first member rotatably connected to a vehicle body; and a second member rotatably connected to the first member; 30
a drive unit having: a first drive device configured to drive the first member; and a second drive device configured to drive the second member; a first sensor configured to detect a first angular position indicating an angular position of the first member; and 35
a second sensor configured to detect a second angular position indicating an angular position of the second member, and
wherein the control device performs: 40

an acquisition process in which the first and second angular positions are acquired while drive control is being performed to control the drive unit; and 45
a coping process in which a measure is taken to avoid interference between the attachment and the vehicle body based on the first and second angular positions acquired in the acquisition process. 50

11. The control device of claim 10, wherein the control device:

stores in advance positional relationship information indicating relationship between (i) the first and second angular positions and (ii) positional relationship between the vehicle body and 55

the attachment;
performs a calculation process in which the positional relationship is calculated by applying the first and second angular positions acquired in the acquisition process to the positional relationship information; and
performs the coping process if the positional relationship calculated in the calculation process indicates that a shortest distance between the attachment and the vehicle body is less than a predetermined value.

12. The control device of claim 11,

wherein the positional relationship information represents relationship between (i) the first and second angular positions and (ii) an index value indicating whether the shortest distance is less than the predetermined value, and
wherein, in the calculation process, the control device calculates the index value as the positional relationship by applying the first and second angular positions acquired in the acquisition process to the positional relationship information.

13. The control device of claim 11,

wherein the positional relationship information includes model information that simulates the working machine in a virtual coordinate system, wherein the model information includes:

vehicle body coordinate information representing position coordinates of various portions of the vehicle body with the vehicle body being placed at a predetermined reference position in the virtual coordinate system;

a first relational equation representing relationship between (i) first coordinate information indicating position coordinates of various portions of the first member and (ii) the first angular position, with the vehicle body being placed at the reference position; and

a second relational equation representing relationship between (I) second coordinate information indicating position coordinates of various portions of the second member and (II) the first and second angular positions, with the vehicle body being placed at the reference position, and

wherein, in the calculation process, the control device applies the first angular position to the first relational equation to calculate the first coordinate information, applies the first and second angular positions to the

second relational equation to calculate the second coordinate information, and calculates the shortest distance as the positional relationship based on the calculated first and second coordinate information and the vehicle body coordinate information. 5

14. A method of controlling a working machine, wherein a control device is applied to a working machine including: 10

an attachment having: a first member rotatably connected to a vehicle body; and a second member rotatably connected to the first member; 15
 a drive unit having: a first drive device configured to drive the first member; and a second drive device configured to drive the second member; a first sensor configured to detect a first angular position indicating an angular position of the first member; and 20
 a second sensor configured to detect a second angular position indicating an angular position of the second member, and wherein the control device performs: 25

an acquisition process in which the first and second angular positions are acquired while drive control is being performed to control the drive unit; and 30
 a coping process in which a measure is taken to avoid interference between the attachment and the vehicle body based on the first and second angular positions acquired in the acquisition process. 35

15. A control program for controlling a working machine, wherein a control device is applied to a working machine including: 40

an attachment having: a first member rotatably connected to a vehicle body; and a second member rotatably connected to the first member; 45
 a drive unit having: a first drive device configured to drive the first member; and a second drive device configured to drive the second member; a first sensor configured to detect a first angular position indicating an angular position of the first member; and 50
 a second sensor configured to detect a second angular position indicating an angular position of the second member, and wherein the control program causes the control device to perform: 55

an acquisition process in which the first and second angular positions are acquired

while drive control is being performed to control the drive unit; and
 a coping process in which a measure is taken to avoid interference between the attachment and the vehicle body based on the first and second angular positions acquired in the acquisition process.

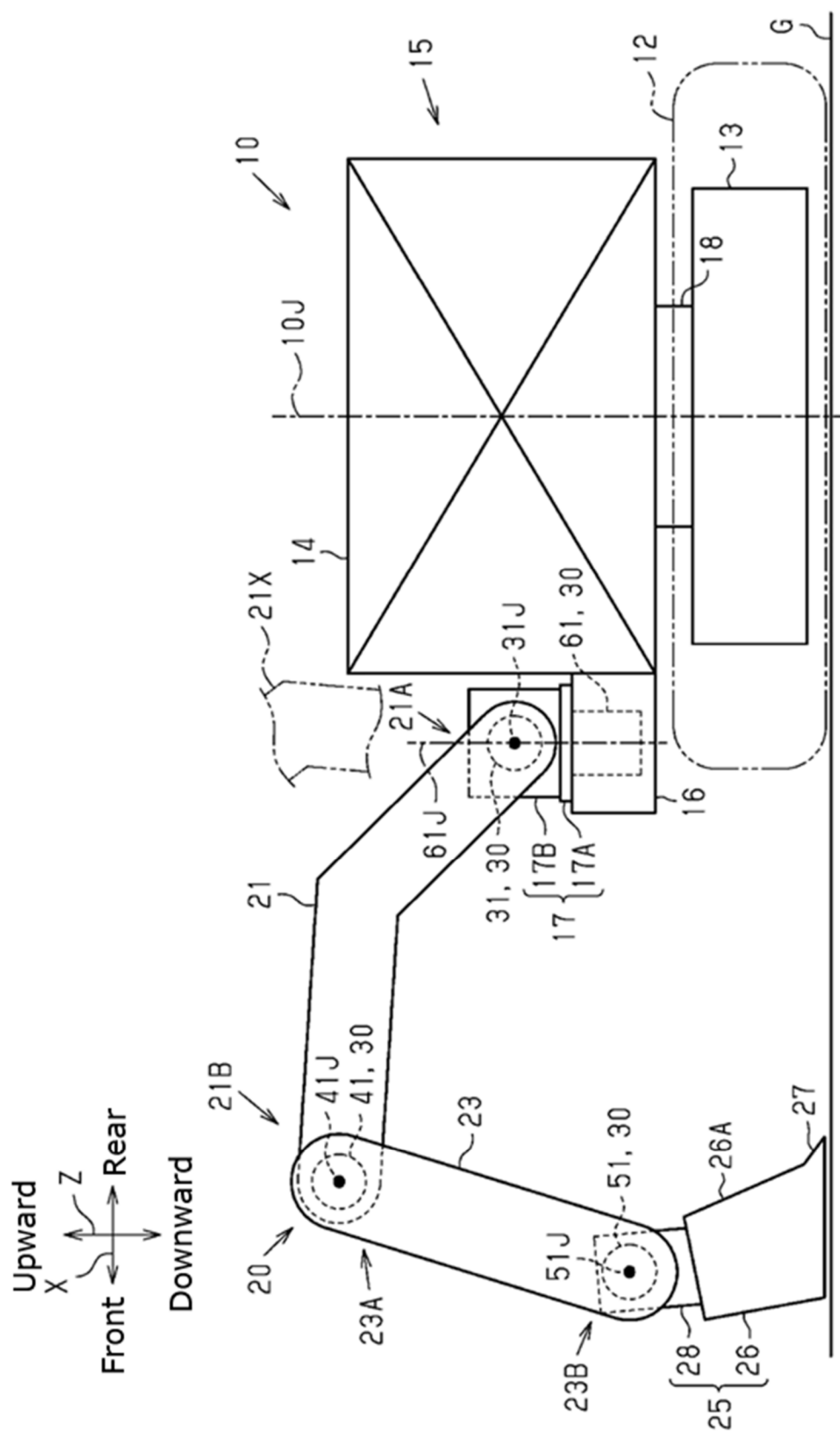


Fig. 1

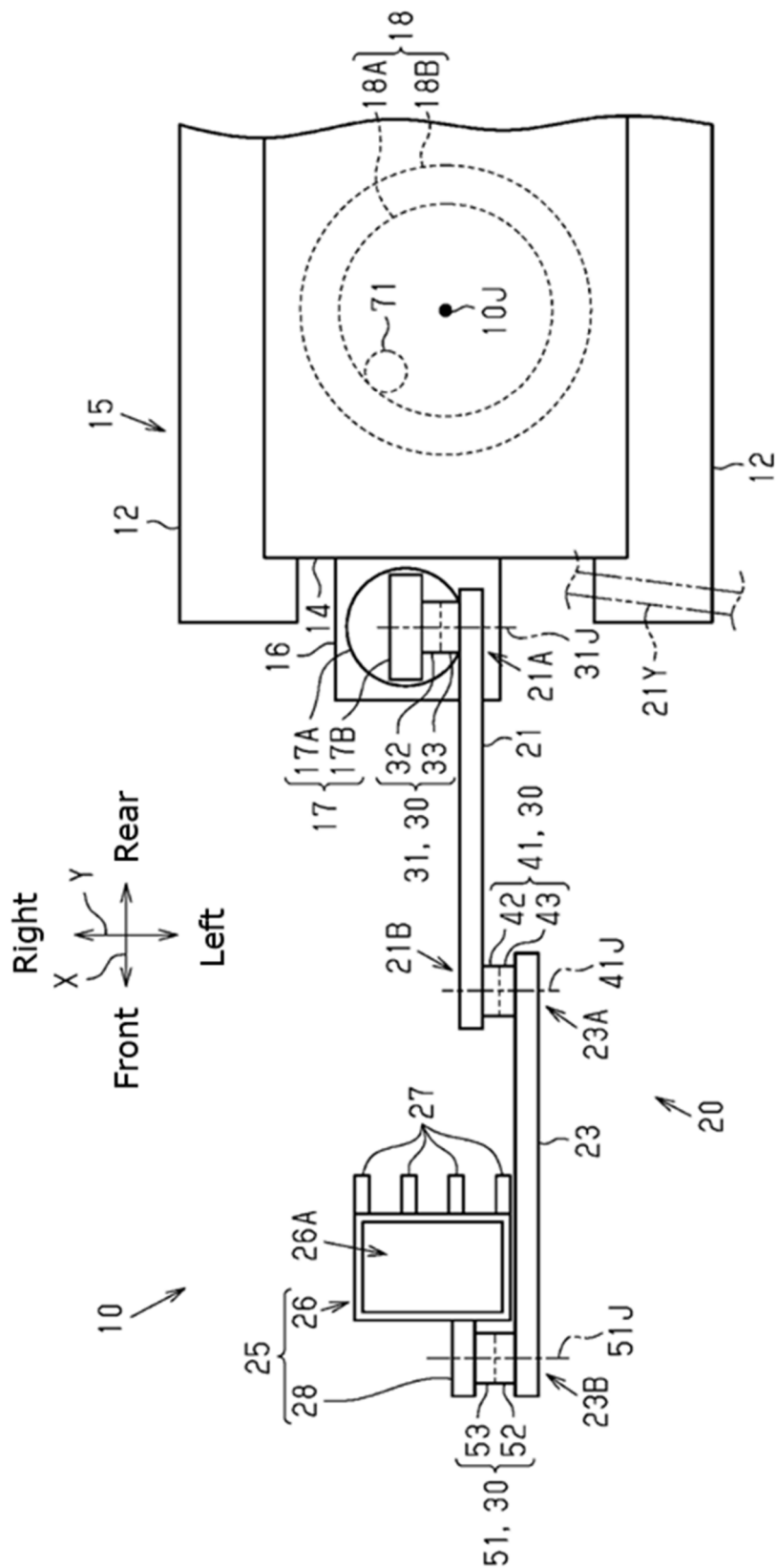


Fig. 2

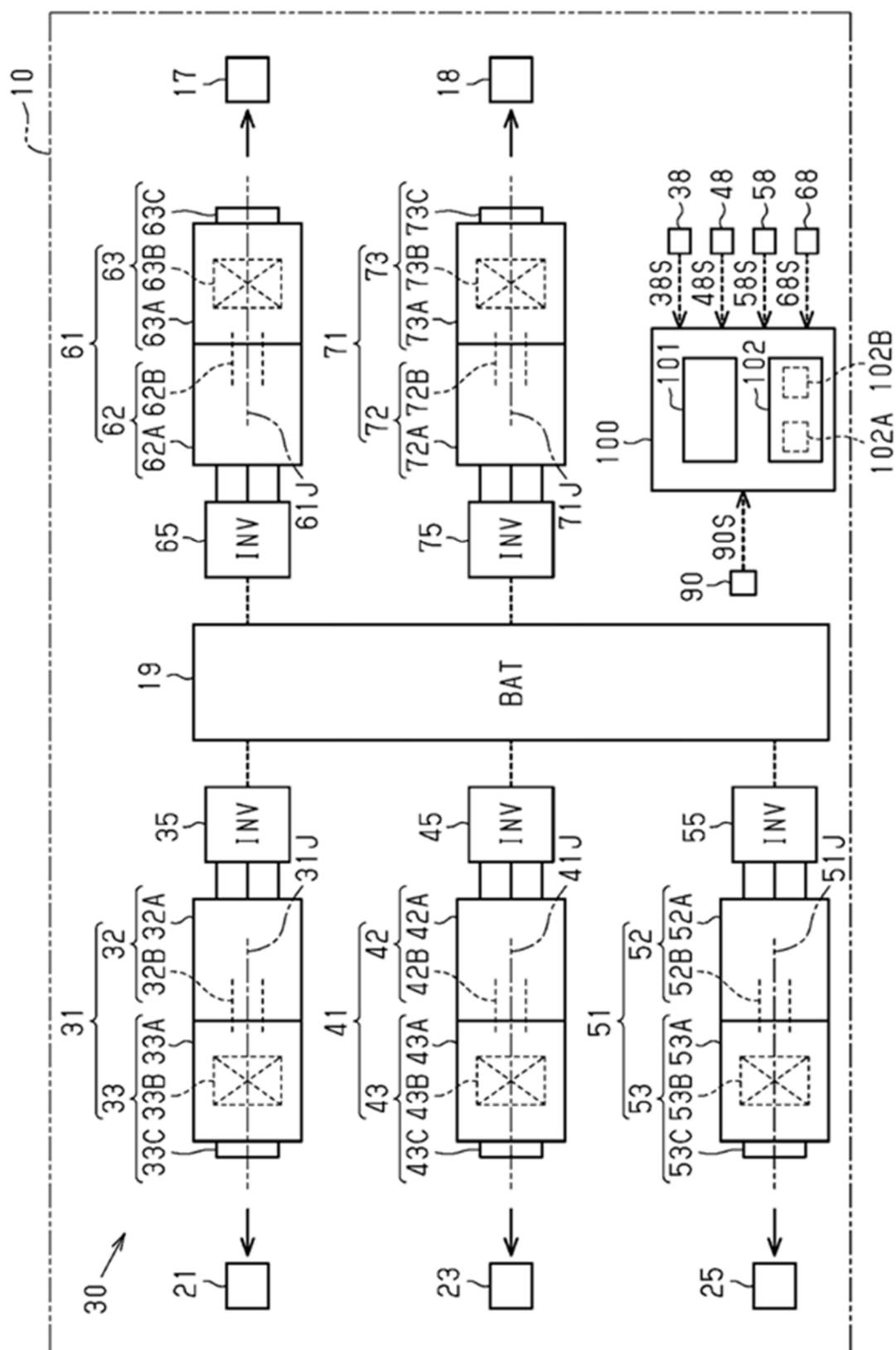


Fig. 3

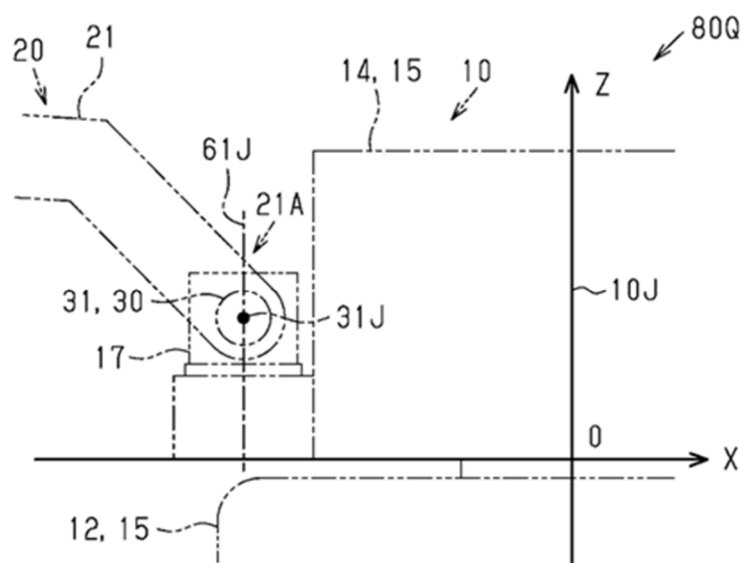


Fig. 4

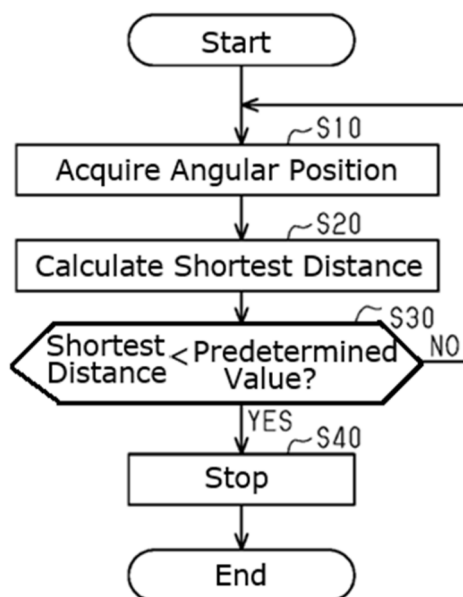


Fig. 5

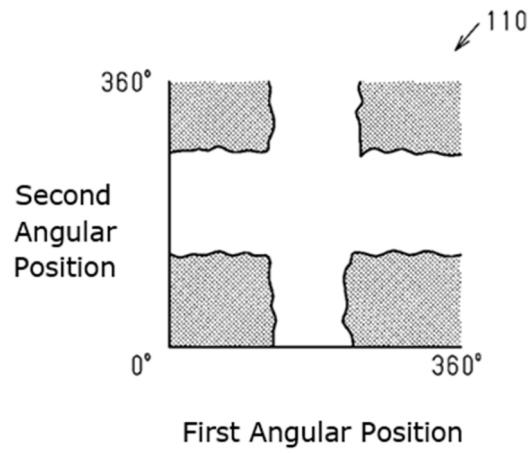


Fig. 6

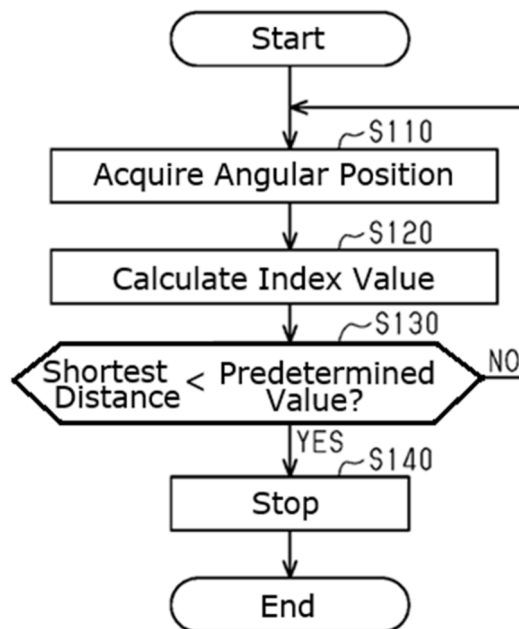


Fig. 7



EUROPEAN SEARCH REPORT

Application Number

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Date of completion of the search			
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