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Robot image display method, recording medium, and robot image display system

Abstract

A robot image display method includes (a) a step of recognizing the position and the posture of a base of a robot from a base section image of a base section for teaching, (b) a step of recognizing the position and the posture of a finger section of the robot from a finger section image of a finger section for teaching, (c) a step of calculating angles of one or more joints of the robot from the position and the posture of the base and the position and the posture of the finger section, and (d) a step of displaying, in a virtual space, a three-dimensional image of the robot in a state in which the joints are at the angles calculated in the step (c).

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Background/Summary

(1) The present application is based on, and claims priority from JP Application Serial Number 2021-068907, filed Apr. 15, 2021, the disclosure of which is hereby incorporated by reference herein in its entirety.
BACKGROUND
1. Technical Field
(2) The present disclosure relates to a robot image display method, a recording medium, and a robot image display system.
2. Related Art
(3) JP-A-2017-104944 (Patent Literature 1) discloses a robot system that, even if an end effector or a robot peripheral device of a robot is absent, can carry out robot teaching work regarding that the end effector or the robot peripheral device is present. This system superimposes and displays a virtual image of the end effector or the robot peripheral device of the robot on a real image of the robot photographed by a camera.
(4) However, in the related art, in order to perform teaching of the robot, it is necessary to actually set the robot and cause a robot arm to actually operate.
SUMMARY
(5) According to a first aspect of the present disclosure, there is provided a robot image display method. The display method includes: (a) a step of acquiring a base section image created by photographing a base section for teaching for teaching a position and a posture of a base of a robot and of recognizing the position and the posture of the base from the base section image; (b) a step of acquiring a finger section image created by photographing a finger section for teaching for teaching a position and a posture of a finger section of the robot and of recognizing the position and the posture of the finger section from the finger section image; (c) a step of calculating angles of joints of the robot from the position and the posture of the base recognized in the step (a) and the position and the posture of the finger section recognized in the step (b); and (d) a step of displaying, in a virtual space, a three-dimensional image of the robot represented by the angles of the joints calculated in the step (c).
(6) According to a second aspect of the present disclosure, there is provided a computer program for performing display processing for a robot image. The computer program causes a processor to execute: (a) processing for acquiring a base section image created by photographing a base section for teaching for teaching a position and a posture of a base of a robot and for recognizing the position and the posture of the base from the base section image; (b) processing for acquiring a finger section image created by photographing a finger section for teaching for teaching a position and a posture of a finger section of the robot and for recognizing the position and the posture of the finger section from the finger section image; (c) processing for calculating angles of joints of the robot from the position and the posture of the base recognized in the processing (a) and the position and the posture of the finger section recognized in the processing (b); and (d) processing for displaying, in a virtual space, a three-dimensional image of the robot represented by the angles of the joints calculated in the processing (c).
(7) According to a third aspect of the present disclosure, there is provided a display system for a robot image. The display system includes: a base section for teaching for teaching a position and a posture of a base of a robot; a finger section for teaching for teaching a position and a posture of a finger section of the robot; a photographing section for photographing the base section for teaching and the finger section for teaching; and a control section connected to the photographing section. The control section executes: (a) processing for acquiring a base section image created by photographing the base section for teaching using the photographing section and for recognizing

the position and the posture of the base from the base section image; (b) processing for acquiring a finger section image created by photographing the finger section for teaching using the photographing section and for recognizing the position and the posture of the finger section from the finger section image; (c) processing for calculating angles of joints of the robot from the position and the posture of the base recognized in the processing (a) and the position and the posture of the finger section recognized in the processing (b); and (d) processing for displaying, in a virtual space, a three-dimensional image of the robot represented by the angles of the joints calculated in the processing (c).

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) FIG. **1** is an explanatory diagram showing a teaching system for a robot in an embodiment.
(2) FIG. **2** is an explanatory diagram showing a base section for teaching and a finger section for teaching and the robot in comparison with each other.
(3) FIG. **3** is a functional block diagram of a control device.
(4) FIG. **4** is an explanatory diagram showing how a robot is displayed in augmented reality in a state shown in FIG. **1**.
(5) FIG. **5** is an explanatory diagram showing another example in which teaching is performed using the teaching system.
(6) FIG. **6** is an explanatory diagram showing how the robot is displayed in augmented reality in a state shown in FIG. **5**.
(7) FIG. **7** is a flowchart showing a procedure of teaching processing in the embodiment.
(8) FIG. **8** is an explanatory diagram showing a robot model selection screen.
(9) FIG. **9** is an explanatory diagram showing how a model of a robot is changed.
(10) FIG. **10** is an explanatory diagram showing a screen for changing joint angles of the robot.
DESCRIPTION OF EXEMPLARY EMBODIMENTS
(11) FIG. **1** is an explanatory diagram showing a teaching system for a robot in an embodiment. The teaching system includes a base section for teaching **110**, a finger section for teaching **130**, an imaging section **200**, a control device **300**, and AR (Augmented Reality) glasses **400**. In this example, the base section for teaching **110** is set on a table **500**. The finger section for teaching **130** is held by a hand PH of an operator PS. The AR glasses **400** are worn on the head of the operator PS. For convenience of illustration, the operator PS is indicated by a broken line. The finger section for teaching **130**, the imaging section **200**, and the AR glasses **400** are connected to the control device **300** by wire or radio. The control device **300** is equivalent to the “control section” in the present disclosure.
(12) The base section for teaching **110** is a member for teaching the position and the posture of a base of the robot. A base section coordinate system Σr**1** having a predetermined reference point of the base section for teaching **110** as the origin is set in the base section for teaching **110**. The finger section for teaching **130** is a member for teaching the position and the posture of a finger section of the robot. A control point TCP (Tool Center Point) is set in the finger section for teaching **130**. A finger section coordinate system Σt**1** having a predetermined reference point as the origin is set in the finger section for teaching **130**. In this example, the origin of the finger section coordinate system Σt**1** is the control point TCP. The teaching system has one characteristic in that the teaching system teaches the movement of the robot using the base section for teaching **110** and the finger section for teaching **130** without using a real machine of the robot. More specifically, first, the teaching system sets the positions of the base section for teaching **110** and the finger section for teaching **130** and, thereafter, photographs images of the base section for teaching **110** and the finger section for teaching **130** with the imaging section **200**, recognizes the positions and the postures of

the base and the finger section of the robot using the images, and calculates angles of joints of the robot. Detailed content of this processing is explained below.

(13) The imaging section **200** photographs images of the base section for teaching **110** and the finger section for teaching **130**. As the imaging section **200**, a stereo camera, an optical ranging device such as Lidar (Laser Imaging Detection and Ranging), a monocular camera, and the like can be used. When the optical ranging device is used, it is preferable to use the monocular camera together with the optical ranging device. Then, there is an advantage that it is possible to accurately calculate, from a distance image obtained by the optical ranging device and a two-dimensional image photographed by the monocular camera, distances in positions in the two-dimensional image. In the imaging section **200**, a camera coordinate system Σc having a predetermined reference point of the imaging section **200** as the origin is set. As shown in FIG. **1**, the imaging section **200** is set above the table **500**. However, the imaging section **200** may be attached to an upper part of the AR glasses **400**.

(14) FIG. **2** is an explanatory diagram showing the base section for teaching **110** and the finger section for teaching **130** and a real machine robot **600** in comparison with each other. The robot **600** includes a base **610** and a robot arm **620** and includes a finger section **630** at the distal end of the robot arm **620**. The finger section **630** may include an end effector or may be a portion not including an end effector such as a hand and provided with a tool flange for attaching the end effector. The end effector is sometimes called "tool". In this embodiment, the robot arm **620** is coupled sequentially by a plurality of joints J**1** to J**6**. As the robot **600**, a robot including any arm mechanism including two or more joints can be used. The robot **600** in this embodiment is a vertical articulated robot. However, a horizontal articulated robot may be used.

(15) In the base **610** of the robot **600**, a robot coordinate system Σr**0** having a predetermined reference point of the base **610** as the origin is set. The robot coordinate system Σr**0** is associated with the base section coordinate system Σr**1** set in the base section for teaching **110**. In the finger section **630**, a control point TCP (Tool Center Point) is set. In the finger section **630** of the robot **600**, a finger section coordinate system Σt**0** having a predetermined reference point as the origin is set. In an example shown in FIG. **2**, the origin of the finger section coordinate system Σt**0** is the control point TCP. The finger section coordinate system Σt**0** is associated with the finger section coordinate system Σt**1** set in the finger section for teaching **130**. The finger section coordinate system Σt**0** may be set with a position other than the control point TCP as the origin. For example, the finger section coordinate system Σt**0** may be set with a reference point of the tool flange at the distal end of the robot arm **620** as the origin. The same applies to the finger section coordinate system Σt**1** set in the finger section for teaching **130**.

(16) The base section for teaching **110** is a member for recognizing the position and the posture of the base **610** of the robot **600**. In this example, the base section for teaching **110** has substantially the same shape as the base **610** of the robot **600**. However, the base section for teaching **110** having any shape can be used. The base section for teaching **110** can be formed using a plate made of metal or plastic or any material such as paper.

(17) A first mark **112** formed by a two-dimensional code is set on the surface of the base section for teaching **110**. The first mark **112** is used to recognize the position and the posture of the base section for teaching **110** from an image of the base section for teaching **110**. The position and the posture of the base section for teaching **110** mean the position and the posture of the base section coordinate system Σr**1** in the camera coordinate system Σc. For example, the first mark **112** can be formed as a black and white pattern including data representing the position and the posture of the base section coordinate system Σr**1** in the camera coordinate system Σc. As explained above, the base section coordinate system Σr**1** set in the base section for teaching **110** corresponds to the robot coordinate system Σr**0** set in the base **610** of the robot **600**. Therefore, the position and the posture of the base section for teaching **110** recognized from the image of the base section for teaching **110** can be regarded the same as the position and the posture of the base **610** of the robot **600**. In

general, the position is represented by three coordinate values and the posture is represented by a 3×3 rotation matrix, a quaternion, or the like. The position and the posture can be represented by a 4×4 homogeneous transformation matrix as well.
(18) The first mark **112** is not limited to the two-dimensional code. For example, a projection, a recess, a light emitting section, or a printed pattern can be used. Then, the position and the posture of the base section for teaching **110** can be easily recognized from an image of the first mark **112**. It is preferable to provide the first mark **112** on a plurality of surfaces of the base section for teaching **110**. However, when the position and the posture of the base section for teaching **110** can be recognized from the shape of the base section for teaching **110**, the first mark **112** can be omitted. In this case, it is preferable to adopt a shape without symmetry as the shape of the base section for teaching **110**. The base **610** of the real machine robot **600** may be used as the base section for teaching **110**.
(19) The finger section for teaching **130** is a member for recognizing the position and the posture of the finger section **630** of the robot **600**. In this example, the finger section for teaching **130** has a shape similar to the shape of the finger section **630** of the robot **600**. However, the finger section for teaching **130** having any shape can be used. The finger section for teaching **130** can be formed using a plate made of metal or plastic or any material such as paper.
(20) A second mark **132** formed by a two-dimensional mark is set on the surface of the finger section for teaching **130**. The second mark **132** is used to recognize the position and the posture of the finger section for teaching **130** from an image of the finger section for teaching **130**. The position and the posture of the finger section for teaching **130** mean the position and the posture of the finger section coordinate system Σt**1** in the camera coordinate system Σc. For example, the second mark **132** can be formed as a black and white pattern including data representing the position and the posture of the finger section coordinate system Σt**1** in the camera coordinate system Σc. As explained above, the finger section coordinate system Σt**1** set in the finger section for teaching **130** corresponds to the finger section coordinate system Σt**0** set in the finger section **630** of the robot **600**. Therefore, the position and the posture of the finger section for teaching **130** recognized from the image of the finger section for teaching **130** can be regarded the same as the position and the posture of the finger section **630** of the robot **600**.
(21) The second mark **132** is not limited to the two-dimensional code. For example, a projection, a recess, a light emitting section, or a printed pattern can be used. Then, the position and the posture of the finger section for teaching **130** can be easily recognized from an image of the second mark **132**. It is preferable to provide the second mark **132** on a plurality of surfaces of the finger section for teaching **130**. However, when the position and the posture of the finger section for teaching **130** can be recognized from the shape of the finger section for teaching **130**, the second mark **132** can be omitted. In this case, it is preferable to adopt a shape without symmetry as the shape of the finger section for teaching **130**. The finger section **630** of the real machine robot **600** may be used as the finger section for teaching **130**.
(22) The finger section for teaching **130** further includes buttons **134** and a force detecting section **136**. In this embodiment, the buttons **134** include two buttons, that is, an A button **134***a* and a B button **134***b*. The buttons **134** can be used to set a teaching point and a route, change a model of the robot, and change joint angles of the robot. For example, to set the teaching point, when the operator PS presses one of the buttons **134**, the position and the posture of the finger section for teaching **130** at a point in time of the pressing of the button are registered as the teaching point. To set the route, when the operator PS moves the finger section for teaching **130** while pressing one of the buttons **134**, a route of the movement of the finger section for teaching **130** is registered. The change of the joint angles is explained below. It is preferable to provide one or more buttons in the finger section for teaching **130**. However, the buttons **134** may be omitted. In this case, an instruction of the operator PS may be given to the control device **300** using a gesture such as a movement of a finger of the operator PS. In this case, it is possible to photograph the gesture of the

operator PS with the AR glasses **400** or the imaging section **200** and recognize the instruction of the operator PS with the control device **300** according to the movement.

(23) The force detecting section **136** is a sensor that measures an external force applied to the finger section for teaching **130**. As the force detecting section **136**, for example, a six-axis force sensor can be used. The force detecting section **136** may be omitted.

(24) Other components such as a display section that displays a teaching state, a switch for generating an enable signal, and a sensor such as a gyroscope for improving recognition accuracy of the position and the posture of the finger section for teaching **130** may be provided in the finger section for teaching **130**. The same hand as a hand of a real machine robot may be used as the finger section for teaching **130**. Alternatively, a wrist section of the real machine robot detached from the robot may be used as the finger section for teaching **130**. In the latter case, the finger section for teaching **130** does not include a portion equivalent to the end effector.

(25) FIG. **3** is a block diagram showing functions of the control device **300**. The control device **300** can be realized as an information processing device such as a personal computer. The control device **300** includes a processor **310**, a memory **320**, an interface circuit **330**, and an input device **340** and a display section **350** coupled to the interface circuit **330**. The finger section for teaching **130**, the imaging section **200**, and the AR glasses **400** are further coupled to the interface circuit **330** by wire or radio. However, when electric components such as the buttons **134** and the force detecting section **136** are not provided in the finger section for teaching **130**, the finger section for teaching **130** may not be connected to the control device **300**.

(26) The processor **310** includes functions of a robot selecting section **312**, a position and posture recognizing section **314**, a joint-angle calculating section **316**, and a control-program creating section **318**. The robot selecting section **312** is used to select one model set as a target of teaching processing from a plurality of models of the robot **600**. The position and posture recognizing section **314** recognizes the position and the posture of the base **610** and the position and the posture of the finger section **630** of the robot **600** from an image obtained by photographing the base section for teaching **110** and the finger section for teaching **130** with the imaging section **200**. The joint-angle calculating section **316** calculates angles of joints of the robot **600** from the position and the posture of the base **610** and the position and the posture of the finger section **630** recognized by the position and posture recognizing section **314**. The control-program creating section **318** creates a control program for the robot **600** using the joint angles calculated by the joint-angle calculating section **316**. The functions of the sections **312**, **314**, **316**, and **318** are realized by the processor **310** executing a computer program stored in the memory **320**. However, a part or all of the functions of the sections may be realized by a hardware circuit.

(27) In the memory **320**, robot attribute data RD, peripheral object attribute data PD, and a robot control program RP are stored. The robot attribute data RD includes, concerning the plurality of models of the robot **600**, various robot characteristics such as the configuration and a movable range of the robot arm **620**. The robot attribute data RD preferably includes three-dimensional data representing a three-dimensional shape of the robot **600** in order to display a three-dimensional image of the robot **600** in augmented reality using the AR glasses **400**. The peripheral object attribute data PD includes three-dimensional data representing a three-dimensional shape of a peripheral object present around the robot **600**. As the peripheral object, for example, a stand, a shelf, a wall, and a parts feeder can be used. The peripheral object attribute data PD may include data representing the shape and the weight of a workpiece treated by the robot **600**. The robot control program RP is formed by a plurality of instructions for causing the robot **600** to operate. The robot control program RP is created by teaching processing explained below.

(28) FIG. **4** is an explanatory diagram showing how the robot **600** is displayed as augmented reality in a state shown in FIG. **1**. A three-dimensional image of the robot **600** is displayed in a superimposed manner on the base section for teaching **110** and the finger section for teaching **130** by the AR glasses **400**. More specifically, the three-dimensional image of the robot **600** is displayed

such that an image of the base **610** is arranged according to the position and the posture of the base **610** recognized using the base section for teaching **110** and an image of the finger section **630** is arranged according to the position and the posture of the finger section **630** recognized using the finger section for teaching **130**. In an example shown in FIG. **4**, for convenience of illustration, display positions of the base **610** and the finger section **630** of the robot **600** are drawn as positions slightly deviating from the positions of the base section for teaching **110** and the finger section for teaching **130**. When the shape of the wrist section not including the end effector is used as the shape of the finger section for teaching **130**, it is preferable to display the end effector as augmented reality as well. It is preferable that a form of the end effector can be switched by moving a movable section of the end effector in a virtual space using one of the buttons **134**. The "virtual space" means an artificial environment created by a computer.
(29) FIG. **5** is an explanatory diagram showing another example in which teaching is performed using the teaching system. FIG. **6** is an explanatory diagram showing how the robot **600** is displayed in augmented reality in a state shown in FIG. **5**. In these examples, the distal end of the finger section for teaching **130** is pressed against a workpiece WK. In this state, when the operator PS presses one of the buttons **134**, the base section for teaching **110** and the finger section for teaching **130** are photographed by the imaging section **200** and force detected by the force detecting section **136** is supplied to the control device **300**. Then, it is possible to simultaneously set preferable force when setting a teaching point. In this case, since the finger section for teaching **130** is held by the hand of the operator PS, it is possible to more easily set the magnitude of the preferable force compared with when force is input as a numerical value in Newton unit. The setting of such preferable force is performed, for example, when the workpiece WK includes a button and a test for pressing the button of the workpiece WK is executed using the robot **600**. Alternatively, when a polishing member is provided in the finger section **630** to polish the workpiece WK as well, setting of force is performed.
(30) FIG. **7** is a flowchart showing a procedure of teaching processing in the embodiment. In step S**10**, the processor **310** selects a model of the robot **600** using the function of the robot selecting section **312**.
(31) FIG. **8** is an explanatory diagram showing a robot model selection screen WS**1**. In this embodiment, the selection screen WS**1** is displayed as augmented reality according to image data supplied from the robot selecting section **312** to the AR glasses **400**. On the selection screen WS**1**, a plurality of models of robots are arrayed as choices. In the models, besides a model name, the number of axes, a maximum reach, and a weight capacity are shown as attributes of the robots. However, a part or all of the attributes of the robots may be omitted. Images of the models may be displayed. The operator PS can select a model using the buttons **134** provided in the finger section for teaching **130**. That is, the operator PS can select one of the plurality of models by pressing the A button **134***a* and determine the model by pressing the B button **134***b*. In a state shown in FIG. **8**, a robot with a model name "C**1**" is selected. A result of the selection by the operator PS is received by the robot selecting section **312**. The operator PS may directly designate a model name to thereby select a model instead of using the selection screen WS**1**.
(32) In step S**20** in FIG. **7**, the position and posture recognizing section **314** photographs the base section for teaching **110** and the finger section for teaching **130** using the imaging section **200** and generates a base section image and a finger section image. Step S**20** is started by the operator PS pressing one of the buttons **134**, for example, the A button **134***a* of the finger section for teaching **130**. The imaging section **200** preferably has a sufficiently wide angle of view to be able to simultaneously photograph the base section for teaching **110** and the finger section for teaching **130**. The base section image and the finger section image may be the same image. Alternatively, in an image photographed by the imaging section **200**, an image portion including the base section for teaching **110** may be extracted as the base section image and another image portion including the finger section for teaching **130** may be extracted as the finger section image. The base section

image and the finger section image may be separately photographed. The base section image and the finger section image are temporarily stored in the memory **320**. The imaging section **200** may photograph a moving image. When the operator PS desires to set a path rather than registering a teaching point, in step S**20**, the imaging section **200** photographs a moving image of the moving finger section for teaching **130**.

(33) In step S**30**, the position and posture recognizing section **314** acquires the base section image obtained in step S**20** from the memory **320** and recognizes the position of the base **610** of the robot **600** from the base section image. In this embodiment, as shown in FIG. **2**, the position and the posture of the base section coordinate system Σr**1** in the camera coordinate system Σc are recognized from an image of the first mark **112** provided in the base section for teaching **110**. The position and the posture of the base section coordinate system Σr**1** can be regarded as the position and the posture of the base **610** of the robot **600**, that is, the position and the posture of the robot coordinate system Σr**0**.

(34) In step S**40**, the position and posture recognizing section **314** acquires the finger section image obtained in step S**20** from the memory **320** and recognizes the position of the finger section **630** of the robot **600** from the finger section image. In this embodiment, as shown in FIG. **2**, the position and the posture of the finger section coordinate system Σt**1** in the camera coordinate system Σc are recognized from an image of the second mark **132** provided in the finger section for teaching **130**. The position and the posture of the finger section coordinate system Σt**1** can be regarded as the position and the posture of the finger section **630** of the robot **600**, that is, the position and the posture of the finger section coordinate system Σt**0**.

(35) In step S**50**, the position and posture recognizing section **314** calculates a robot coordinate of the control point TCP of the finger section **630** from the position and posture of the base **610** and the position and the posture of the finger section **630** of the robot **600**. The robot coordinate of the control point TCP is represented by the position and the posture of the finger section coordinate system Σt**0** in the robot coordinate system Σr**0**.

(36) In step S**60**, the robot selecting section **312** determines whether the model of the robot **600** needs to be changed. Specifically, when the robot coordinate of the control point TCP calculated in step S**50** is within a movable range in the currently selected model of the robot **600**, the robot selecting section **312** determines that the model does not need to be changed. On the other hand, when the robot coordinate of the control point TCP is outside the movable range, the robot selecting section **312** determines that the model needs to be changed. When the model does not need to be changed, the processor **310** proceeds to step S**80** explained below. When the model needs to be changed, the processor **310** proceeds to step S**70**. In step S**70**, the processor **310** changes the model of the robot **600** using the function of the robot selecting section **312**.

(37) FIG. **9** is an explanatory diagram showing how the type of the robot is changed using the robot model selection screen WS**1**. In FIG. **9**, among the plurality of models, “C**1**” and “D**1**” are models in which the robot coordinate of the control point TCP is outside the movable range. The models “C**1**” and “D**1**” are displayed such that the operator PS can visually recognize that the models “C**1**” and “D**1**” are ineffective choices that cannot be selected. In an example shown in FIG. **9**, the models “C**1**” and “D**1**” are hatched. Boxes for selection of the models “C**1**” and “D**1**” cannot be selected either. The other models are presented as a list of effective choices that can be selected. The operator PS can change the model of the robot **600** by selecting one out of the effective choices. In the example shown in FIG. **9**, a model “C**2**” is selected as a model after the change. In this way, when the control point TCP of the finger section **630** is outside the movable range, it is possible to put the control point TCP within the movable range of the robot **600** by changing the model of the robot **600**. A plurality of effective choices do not need to be displayed. However, it is preferable that one or more effective choices are displayed. The control point TCP determined whether being outside the movable range does not have to be only the control point TCP calculated in step S**50**. For example, the control point TCP stored before step S**50**, that is, the control point

TCP stored in teaching processing in the past may be added. In this case, among the plurality of models, a model in which at least one of a plurality of control points TCP is outside the movable range may be determined as an ineffective choice that cannot be selected and may be hatched.
(38) In this way, in step S**70**, as the model of the robot **600**, one or more models in which the position of the control point TCP in the robot coordinate system Σr**0** is within the movable range of the robot **600** are presented to the operator PS. A model selected out of the one or more models by the operator PS is adopted. Then, the model of the robot **600** can be easily changed. The operator PS may change the model by directly designating a model name instead of using the selection screen WS**1**.
(39) In step S**80**, the joint-angle calculating section **316** calculates angles of the joints of the robot **600** from the position and the posture of the control point TCP in the robot coordinate system Σr**0**. The calculation is executed according to inverse kinematics. In general, as a combination of the angles of the joints calculated by the inverse kinematics, a plurality of combinations are often possible. In this case, in step S**80**, one combination is selected out of the plurality of combinations according to a predetermined rule.
(40) In step S**90**, the joint-angle calculating section **316** determines whether the joint angles need to be changed. In this embodiment, when the shape of the robot arm **620** represented by the angles of the joints is in an interference state in which the shape of the robot arm **620** is likely to interfere with a peripheral object in a virtual space, the joint-angle calculating section **316** determines that the joint angles need to be changed. The external shape of the peripheral object is represented by three-dimensional data included in the peripheral object attribute data PD stored in the memory **320**. The joint-angle calculating section **316** is capable of calculating a distance between the external shape of the peripheral object represented by the three-dimensional data of the peripheral object and the shape of the robot arm **620** represented by the joint angles calculated in step S**80**, when the distance is equal to or smaller than a predetermined threshold, determining that the shape of the robot arm **620** is in the interference state, and determining that the joint angles need to be changed. As the threshold, for example, a value equal to or larger than 0 and equal to or smaller than 10 cm is set. When the peripheral object and the shape of the robot arm **620** are not in the interference state in the virtual space, the joint-angle calculating section **316** determines that the joint angles do not need to be changed. When the shape of the robot arm **620** is in the interference state in which the shape of the robot arm **620** is likely to interfere with the peripheral object, the joint-angle calculating section **316** may notify an alert indicating that the shape of the robot arm **620** is in the interference state to the operator PS. When the joint angles do not need to be changed, the processor **310** proceeds to step S**110** explained below. When the joint angles need to be changed, the processor **310** proceeds to step S**100**. In step S**100**, the processor **310** changes the joint angles of the robot **600** using the function of the joint-angle calculating section **316**.
(41) FIG. **10** is an explanatory diagram showing a screen WS**2** for changing the joint angles of the robot. In this embodiment, the screen WS**2** is displayed as augmented reality according to image data supplied from the joint-angle calculating section **316** to the AR glasses **400**. In this example, two choices are displayed as combinations of the joint angles. In an angle A**1** and an angle A**2**, combinations of angles of three joints J**2**, J**3**, and J**5** are different from one another but the position and the posture of the finger section **630** are the same. In the angle A**1**, the robot arm **620** is likely to interfere with a peripheral object PB. In the angle A**2**, the robot arm **620** is unlikely to interfere with the peripheral object PB. Therefore, in this example, the angle A**2** is selected as a combination of the joint angles after the change. In this way, the joint angles can be changed by selecting one out of a plurality of choices concerning the combinations of the joint angles. Such a change of the joint angles is performed to maintain the position and the posture of the finger section **630**. The change of the joint angles is performed according to an instruction of the operator PS. As a result, when the shape of the robot arm **620** is in the interference state in which the shape of the robot arm **620** is likely to interfere with the peripheral object PB in the virtual space, it is possible to eliminate

the interference state by changing the joint angles. Instead of the operator PS selecting one of the choices, the joint-angle calculating section **316** may automatically determine a combination of the joint angles for eliminating the interference state.

(42) The joint-angle calculating section **316** does not need to automatically perform the determination in step S**90**. Instead, when the operator PS designates necessity of a change of the joint angles, the joint-angle calculating section **316** may determine that the joint angles need to be changed. That is, the operator PS may view images of the robot arm **620** and the peripheral object PB and determine whether the shape of the robot arm **620** and the peripheral object PB are in the interference state. In this case as well, it is preferable that the operator PS selects combinations of the joint angles. Then, the operator PS can freely select a preferable state of the robot arm **620**.

(43) In step S**110**, the joint-angle calculating section **316** displays an image of the robot **600** in the virtual space. In this embodiment, the robot **600** is displayed as augmented reality according to image data supplied from the joint-angle calculating section **316** to the AR glasses **400**. For example, as shown in FIGS. **4** and **6** referred to above, in a three-dimensional image of the robot **600**, an image of the base **610** of the robot **600** is displayed in a superimposed manner on the base section for teaching **110** and an image of the finger section **630** of the robot **600** is displayed in a superimposed manner on the finger section for teaching **130**.

(44) In step S**120**, the operator PS determines whether a state of the robot **600** displayed in step S**110** is appropriate as a teaching point. When the state of the robot **600** is inappropriate as the teaching point, the processor **310** return to step S**20**. The operator PS changes the position of the finger section for teaching **130** and, then, executes photographing of an image again. On the other hand, when the state of the robot **600** is appropriate as the teaching point, the processor **310** proceeds step S**130**.

(45) In step S**130**, the control-program creating section **318** registers, as the teaching point, a state in which the image is photographed in step S**20**. Step S**130** is started by the operator PS pressing one of the buttons **134**, for example, the B button **134***b* of the finger section for teaching **130**. The teaching point is registered in the robot control program RP in the memory **320**. When the operator PS desires to set a path rather than registering the teaching point, that is, when the operator PS photographs a moving image, the control-program creating section **318** generates a plurality of still images from the moving image in time series order and records states of the still images as teaching points. The control-program creating section **318** generates a path from a plurality of teaching points recorded in this way.

(46) In step S**140**, the operator PS determines whether the teaching processing has ended. When the teaching processing has not ended, the processor **310** returns to step S**20**. The operator PS changes the position of the finger section for teaching **130** and, then, executes photographing of an image again. On the other hand, when the teaching processing has ended, the processor **310** ends the processing shown in FIG. **7**.

(47) After the processing shown in FIG. **7**, the processor **310** may execute, as a part of the teaching processing, processing for setting other setting items for the robot control program RP. After the teaching processing ends, the processor **310** may reproduce the operation of the robot **600** in the virtual space using the robot control program RP created by the teaching processing. For example, when work for conveying a workpiece is performed using the robot **600**, the processor **310** may store the shape and the weight of the workpiece in the memory **320** in advance and reproduce, in the virtual space, a state in which the robot **600** conveys the workpiece. Then, without causing the robot **600** to actually operate, the operator PS can determine whether the work for conveying the workpiece is appropriate. After changing the joint angles of the robot **600** in step S**100**, the processor **310** displays the image of the robot **600** in the virtual space in step S**110**. However, the processor **310** may display the image of the robot **600** in the virtual space after step S**80** and, thereafter, determine whether to change the joint angles of the robot **600**. In such a case, the display and the change may be repeated about a plurality of joint angles. In particular, in a robot having

high redundancy flexibility like a vertical articulated robot, optimum joint angles can be selected out of the plurality of joint angles.
(48) As explained above, in the embodiment, the position and the posture of the base **610** of the robot **600** are recognized from the image of the base section for teaching **110**, the position and the posture of the finger section **630** of the robot **600** are recognized from the image of the finger section for teaching **130**, the angles of the joints of the robot **600** are calculated using the positions and the postures, and the three-dimensional image of the robot **600** represented by the calculated angles of the joints is displayed in the virtual space. Therefore, without actually setting the robot **600** or causing the robot **600** to operate, the operator PS can easily understand to what kind of a state the robot arm **620** changes and can perform teaching of the robot **600**.
(49) In the embodiment explained above, the three-dimensional images of the robot **600** and the peripheral object PB are displayed as virtual reality using the AR glasses **400**. However, instead, images of the robot **600** and the peripheral object PB may be displayed in the virtual space using the display section **350** that displays a two-dimensional image. In this case as well, the image of the robot **600** is displayed in the virtual space as in the case in which the AR glasses **400** are used. However, if the three-dimensional image of the robot **600** is displayed in augmented reality using the AR glasses **400**, there is an advantage that the operator PS can easily understand the posture of the robot **600**.
OTHER EMBODIMENTS
(50) The present disclosure is not limited to the embodiment explained above and can be realized in various aspects in a range not departing from the gist of the present disclosure. For example, the present disclosure can also be realized in aspects described below. Technical features in the embodiment corresponding to technical features in the aspects described below can be replaced or combined as appropriate in order to solve a part or all of the problems of the present disclosure or achieve a part or all of the effects of the present disclosure. If the technical features are not explained as essential technical features in this specification, the technical features can be deleted as appropriate.
(51) According to a first aspect of the present disclosure, there is provided a robot image display method. The display method includes: (a) a step of acquiring a base section image created by photographing a base section for teaching for teaching a position and a posture of a base of a robot and of recognizing the position and the posture of the base from the base section image; (b) a step of acquiring a finger section image created by photographing a finger section for teaching for teaching a position and a posture of a finger section of the robot and of recognizing the position and the posture of the finger section from the finger section image; (c) a step of calculating angles of joints of the robot from the position and the posture of the base recognized in the step (a) and the position and the posture of the finger section recognized in the step (b); and (d) a step of displaying, in a virtual space, a three-dimensional image of the robot represented by the angles of the joints calculated in the step (c).
(52) With the display method, without actually setting the robot or causing the robot to operate, an operator can easily understand to what kind of a state a robot arm changes and perform teaching of the robot.
(53) (2) In the display method, the step (c) may include: (i) a step of calculating, in a robot coordinate system, a position of a control point set in the finger section from the position and the posture of the base recognized in the step (a) and the position and the posture of the finger section recognized in the step (b); and (ii) a step of changing a model of the robot when the position of the control point in the robot coordinate system is outside a movable range of the robot.
(54) With the display method, when the control point of the finger section is outside the movable range of the robot, it is possible to put the control point of the finger section within the movable range of the robot by changing the model of the robot.
(55) (3) In the display method, the step (ii) may include: presenting, as the model of the robot, to an

operator, one or more models in which the position of the control point in the robot coordinate system is within the movable range of the robot; and adopting a model selected by the operator out of the one or more models.
(56) With the display method, it is possible to easily change the model of the robot.
(57) (4) In the display method, the step (c) may include an angle changing step for, when a plurality of combinations are possible as a combination of the angles of the joints, selecting one combination out of the plurality of combinations and changing the combination.
(58) With the display method, it is possible to select a preferable state as a state of the robot arm.
(59) (5) In the display method, an operator may perform the selection of the combination of the angles of the joints.
(60) With the display method, the operator can freely select a preferable state of the robot arm.
(61) (6) In the display method, the angle changing step may include an interference eliminating step for, when a shape of a robot arm represented by the angles of the joints calculated in the step (c) is in an interference state in which the shape of the robot arm interferes with a peripheral object, eliminating the interference state by changing the combination of the angles of the joints while maintaining the position and the posture of the finger section.
(62) With the display method, it is possible to reduce possibility of the robot arm and the peripheral object interfering with each other.
(63) (7) In the display method, the interference eliminating step may include: calculating a distance between the peripheral object represented by a three-dimensional data of the peripheral object and the shape of the robot arm represented by the angles of the joints calculated in the step (c); and determining that the shape of the robot arm is in the interference state when the distance is equal to or smaller than a predetermined threshold and automatically determining a combination of the angles of the joints for eliminating the interference state while maintaining the position and the posture of the finger section.
(64) With the display method, it is possible to automatically eliminate the interference of the robot arm and the peripheral object.
(65) (8) The display method may further includes displaying the three-dimensional image in a superimposed manner on the base section for teaching and the finger section for teaching as augmented reality in the step (d).
(66) With the display method, since the robot arm is displayed as augmented reality, the operator can easily understand to what kind of a state the robot arm changes.
(67) (9) In the display method, a first mark used to recognize the position and the posture of the base of the robot may be provided in the base section for teaching, and a second mark used to recognize the position and the posture of the finger section of the robot may be provided in the finger section for teaching.
(68) With the display method, it is possible to easily recognize the position and the posture of the base and the position and the posture of the finger section using the first mark and the second mark.
(69) (10) In the display method, each of the first mark and the second mark may include a two-dimensional code, a projection, a recess, a light emitting section, or a printed pattern.
(70) With the display method, it is possible to easily recognize the position and the posture of the base and the position and the posture of the finger section from the first mark and the second mark.
(71) (11) According to a second aspect of the present disclosure, there is provided a computer program for performing display processing for a robot image. The computer program causes a processor to execute: (a) processing for acquiring a base section image created by photographing a base section for teaching for teaching a position and a posture of a base of a robot and for recognizing the position and the posture of the base from the base section image; (b) processing for acquiring a finger section image created by photographing a finger section for teaching for teaching a position and a posture of a finger section of the robot and for recognizing the position and the posture of the finger section from the finger section image; (c) processing for calculating angles of

joints of the robot from the position and the posture of the base recognized in the processing (a) and the position and the posture of the finger section recognized in the processing (b); and (d) processing for displaying, in a virtual space, a three-dimensional image of the robot represented by the angles of the joints calculated in the processing (c).
(72) With the computer program, without actually setting the robot or causing the robot to operate, an operator can easily understand to what kind of a state a robot arm changes and perform teaching of the robot.
(73) (12) According to a third aspect of the present disclosure, there is provided a display system for a robot image. The display system includes: a base section for teaching for teaching a position and a posture of a base of a robot; a finger section for teaching for teaching a position and a posture of a finger section of the robot; a photographing section for photographing the base section for teaching and the finger section for teaching; and a control section connected to the photographing section. The control section executes: (a) processing for acquiring a base section image created by photographing the base section for teaching using the photographing section and for recognizing the position and the posture of the base from the base section image; (b) processing for acquiring a finger section image created by photographing the finger section for teaching using the photographing section and for recognizing the position and the posture of the finger section from the finger section image; (c) processing for calculating angles of joints of the robot from the position and the posture of the base recognized in the processing (a) and the position and the posture of the finger section recognized in the processing (b); and (d) processing for displaying, in a virtual space, a three-dimensional image of the robot represented by the angles of the joints calculated in the processing (c).
(74) With the teaching system, without actually setting the robot or causing the robot to operate, an operator can easily understand to what kind of a state a robot arm changes and perform teaching of the robot.
(75) The present disclosure can be realized in various aspects other than the aspects described above. For example, the present disclosure can be realized in aspects of a robot system including a robot and a control device, a computer program for realizing functions of the control device for the robot, and a non-transitory storage medium recording the computer program.

Claims

1. A display method for causing a processor to execute a process, the display method comprising executing on the processor the steps of: adopting a first model of a plurality of models of a robot, the first model being selected by an operator among the plurality of models; acquiring a teaching base image created by photographing only a teaching base section while the teaching base section is placed at a teaching table in a real space, the teaching base section corresponding to a base of the robot located in the real space, the teaching base section being provided in addition to the base of the robot; recognizing a first position and a first posture of the base of the robot based on the teaching base image; creating a virtual base image of a virtual robot in a virtual space based on the first position and the first posture; acquiring a teaching finger image created by photographing only a teaching finger section while the teaching finger section is held by the operator and placed above the teaching table in the real space, the teaching finger section corresponding to a finger of the robot, the teaching finger section being provided in addition to the finger of the robot; recognizing a second position and a second posture of the finger of the robot based on the teaching finger image; creating a virtual finger image of the virtual robot in the virtual space based on the second position and the second posture; calculating angles of a plurality of joints of an arm of the robot based on the first position, the first posture, the second position, and the second posture; creating a virtual arm of the virtual robot in the virtual space, the virtual arm having a plurality of virtual joints respectively positioned in consideration of the calculated angles; and displaying, in the

virtual space, a three-dimensional image of the virtual robot having the created virtual base image, the created virtual finger image, and the created virtual arm, wherein, in the calculating of the angles: a position of a control point set in the finger of the robot is calculated in a robot coordinate system from the first position and the first posture of the base of the robot and the second position and the second posture of the finger of the robot; the processor is further configured to determine whether the position of the control point in the robot coordinate system is outside a movable range of the first model of the robot; and the first model of the robot is changed under a condition in which the position of the control point in the robot coordinate system is outside the movable range of the first model of the robot, and wherein the display method further including executing on the processor the steps of: presenting one or more models of the plurality of models of the robot in which the position of the control point in the robot coordinate system is within the movable range of the robot- to the operator; and adopting another model, the another model being selected by the operator among the presented one or more models of the plurality of models of the robot.

2. The display method according to claim 1, wherein the calculating of the angles includes: when a plurality of combinations are possible as a combination of the angles of the joints, selecting one combination out of the plurality of combinations and changing the angles.

3. The display method according to claim 2, wherein the selection of the one combination of the angles of the joints is performed the operator.

4. The display method according to claim 2, wherein when a shape of the arm of the robot represented by the angles of the joints is in an interference state in which the shape of the arm interferes with a peripheral object, the interference state is eliminated by changing the combination of the angles of the joints while maintaining the second position and the second posture of the finger.

5. The display method according to claim 4, wherein when the interference state is eliminated, a distance between the peripheral object represented by a three-dimensional data of the peripheral object and the shape of the arm in which the joints are at the calculated angles, it is determined that the shape of the arm is in the interference state when the distance is equal to or smaller than a predetermined threshold, and a combination of the angles of the joints for eliminating the interference state is automatically determined while maintaining the second position and the second posture of the finger.

6. The display method according to claim 1, wherein the three-dimensional image of the virtual robot is displayed in a superimposed manner on the created virtual base image and the created virtual finger as augmented reality in the virtual space.

7. The display method according to claim 1, wherein a first mark used to recognize the first position and the first posture of the base of the robot is provided in the teaching base section, and a second mark used to recognize the second position and the second posture of the finger of the robot is provided in the teaching finger section.

8. The display method according to claim 7, wherein each of the first mark and the second mark includes a two-dimensional code, a projection, a recess, a light emitting section, or a printed pattern.

9. A non-transitory recording medium recording a computer program for causing a computer to execute a process by a processor so as to perform the steps of: adopting a first model of a plurality of models of a robot, the first model being selected by an operator among the plurality of models; acquiring a teaching base image created by photographing only a teaching base section while the teaching base section is placed at a teaching table in a real space, the teaching base section corresponding to a base of the robot located in the real space, the teaching base section being provided in addition to the base of the robot; recognizing a first position and a first posture of the base of the robot based on the teaching base image; creating a virtual base image of a virtual robot in a virtual space based on the first position and the first posture; acquiring a teaching finger image created by photographing only a teaching finger section while the teaching finger section is held by

the operator and placed above the teaching table in the real space, the teaching finger section corresponding to a finger of the robot, the teaching finger section being provided in addition to the finger of the robot; recognizing a second position and a second posture of the finger of the robot based on the teaching finger image; creating a virtual finger image of the virtual robot in the virtual space based on the second position and the second posture; calculating angles of a plurality of joints of an arm of the robot based on the first position, the first posture, the second position, and the second posture; creating a virtual arm of the virtual robot in the virtual space, the virtual arm having a plurality of virtual joints respectively positioned in consideration of the calculated angles; and displaying, in the virtual space, a three-dimensional image of the virtual robot having the created virtual base image, the created virtual finger image, and the created virtual arm, wherein, in the calculating of the angles: a position of a control point set in the finger of the robot is calculated in a robot coordinate system from the first position and the first posture of the base of the robot and the second position and the second posture of the finger of the robot; the processor is further configured to determine whether the position of the control point in the robot coordinate system is outside a movable range of the first model of the robot; and the first model of the robot is changed under a condition in which the position of the control point in the robot coordinate system is outside the movable range of the first model of the robot, and wherein the processor is further configured to: present one or more models of the plurality of models of the robot in which the position of the control point in the robot coordinate system is within the movable range of the robot to the operator; and adopt another model, the another model being selected by the operator among the presented one or more models of the plurality of models of the robot.

10. A display system comprising: a display; a camera; a processor configured to be programed to: adopt a first model of a plurality of models of a robot, the first model being selected by an operator among the plurality of models; acquire a teaching base image created by photographing only a teaching base section via the camera while the teaching base section is placed at a teaching table in a real space, the teaching base section corresponding to a base of the robot located in the real space, the teaching base section being provided in addition to the base of the robot; recognize a first position and a first posture of the base of the robot based on the teaching base image; create a virtual base image of a virtual robot in a virtual space based on the first position and the first posture; acquire a teaching finger image created by photographing only a teaching finger section via the camera while the teaching finger section is held by the operator and placed above the teaching table in the real space, the teaching finger section corresponding to a finger of the robot, the teaching finger section being provided in addition to the finger of the robot; recognize a second position and a second posture of the finger of the robot based on the teaching finger image; create a virtual finger image of the virtual robot in the virtual space based on the second position and the second posture; calculate angles of a plurality of joints of an arm of the robot based on the first position, the first posture, the second position, and the second posture; create a virtual arm of the virtual robot in the virtual space, the virtual arm having a plurality of virtual joints respectively positioned in consideration of the calculated angles; and display on the display, in a virtual space, a three-dimensional image of the virtual robot having the created virtual base image, the created virtual finger image, and the created virtual arm, wherein, in the calculation of the angles: a position of a control point set in the finger of the robot is calculated in a robot coordinate system from the first position and the first posture of the base of the robot and the second position and the second posture of the finger of the robot; the processor is further configured to determine whether the position of the control point in the robot coordinate system is outside a movable range of the first model of the robot; and the first model of the robot is changed under a condition in which the position of the control point in the robot coordinate system is outside the movable range of the first model of the robot, and wherein the processor is further configured to: present one or more models of the plurality of models of the robot in which the position of the control point in the robot coordinate system is within the movable range of the robot to the operator; and adopt another

model, the another model being selected by the operator among the presented one or more models of the plurality of models of the robot.