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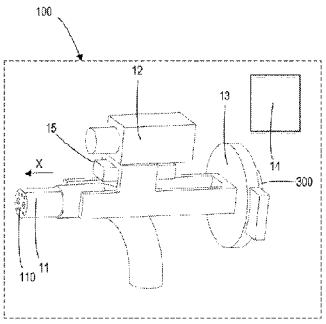


FIG. 3

(57) Abstract: An apparatus (100) and a method for charging an electric vehicle (200), and a method for calibrating an apparatus (100) for charging an electric vehicle (200),the apparatus (100) comprises a charging head (11) arranged on an end executor (300) of a robot and configured to match with a charging port (21) on the electric vehicle (200); a camera (12) arranged on the end executo r(300) and configured to capture an image of the charging port (21); a force sensor (13) arranged on the end executor (300) and configured to detect a force condition of the charging head (11); and a controller (14) configured to: determine a position of the charging port (21) based on the image of the charging port (21); determine a starting position for plugging the charging head (11) into the charging por t(21) based on the position of the charging port (21); cause the end executor(300) to move the charging head (11) towards the starting position; and in response to the charging head (11) reaching the starting position, cause the end executor (300) to move the charging head (11) based on the force condition of the charging head (11) until the plugging of the charging head (11) is completed.

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APPARATUS AND METHOD FOR CHARGING ELECTRIC VEHICLE, AND METHOD FOR CALIBRATING APPARATUS FOR CHARGING ELECTRIC VEHICLE

FIELD

[0001] Embodiments of present disclosure generally relate to charging of an electric vehicle, and more particularly, to an apparatus and a method for charging an electric vehicle, and a method for calibrating an apparatus for charging an electric vehicle.

BACKGROUND

[0002] Nowadays, electric vehicles (EVs) are more and more widely used due to their excellent power saving and environmental performance. The EV typically includes a battery and a charging port arranged on a body surface of the vehicle. In case the battery needs to be charged by an external power supply, an operator may catch a charging head and insert it into the charging port.

[0003] Since the battery typically has a limited capacity and needs a long time to be charged, the EV is typically not suitable for a long distance travel. High capacity battery and high power fast charging are some solutions to these issues. However, with increasing of the charging power (e.g., 350KW), the charging head and its corresponding cable are getting much heavier and are difficult for the operator to handle their plugging/unplugging comfortably.

[0004] An automatic electromechanical device, e.g., a robot, may be used to facilitate the plugging of the charging head into the charging port. In a typical robot assisted EV charging system, the position of the charging port may be detected by means of various sensors. Then, the robot holds the charging head and inserts it into the charging port according to the detected position of the charging port. However, there are many challenges in this process.

[0005] In the conventional EV charging system, the charging head and the charging port are designed with a very tight tolerance and a long mating distance. With such an arrangement, during the plugging process, a typical challenge is that contact forces and torques are generated due to physical dimension irregularity and

misalignment between the charging head and the charging port. In the conventional EV charging system, the contact forces/torques cannot be predicted and responded fast and accurately. Thus, there is a risk that the plugging process may fail and the charging head and the charging port may be damaged during the plugging process.

SUMMARY

[0006] Embodiments of the present disclosure provide an apparatus and a method for charging an electric vehicle, and a method for calibrating an apparatus for charging an electric vehicle.

[0007] In a first aspect, an apparatus for charging an electric vehicle is provided. The apparatus comprises a charging head arranged on an end executor of a robot and configured to match with a charging port on the electric vehicle; a camera arranged on the end executor and configured to capture an image of the charging port; a force sensor arranged on the end executor and configured to detect a force condition of the charging head; and a controller configured to: determine a position of the charging port based on the image of the charging port; determine a starting position for plugging the charging head into the charging port based on the position of the charging port; cause the end executor to move the charging head towards the starting position; and in response to the charging head reaching the starting position, cause the end executor to move the charging head based on the force condition of the charging head until the plugging of the charging head is completed.

[0008] In embodiments of the present disclosure, the movement of the charging head can be controlled based on its force condition during the plugging process, thereby avoiding the plugging failure and reducing the physical damage to the charging apparatus.

[0009] In some embodiments, the controller is configured to cause the end executor to move the charging head based on the force condition of the charging head by: in response to the force condition indicating that a lateral force in a direction intersecting with a plugging direction of the charging head exceeds a first threshold, causing the end executor to move the charging head to reduce the lateral force; and in response to the force condition indicating that a vertical force in a direction opposite

to the plugging direction exceeds a second threshold, causing the end executor to stop moving.

[0010] In some embodiments, the apparatus further comprises a range sensor arranged on the end executor and configured to detect a distance between the charging port and the range sensor, wherein the controller is further configured to determine the position of the charging port based on the image of the charging port and the detected distance.

[0011] In some embodiments, the range sensor comprises an ultrasonic sensor or a laser sensor.

[0012] In some embodiments, the controller is configured to determine the position of the charging port based on the image of the charging port by: causing the camera to capture an initial image of the charging port; determining a center point of the charging port in the initial image; causing the camera to capture a plurality of intermediate images of the charging port from different angles around the center point; determining a pose of the charging port based on the plurality of intermediate images; causing the end executor to move based on the pose of the charging port such that an image plane of the camera is parallel to a surface of the charging port; causing the camera to capture a final image of the charging port; and determining the position of the charging port based on the final image.

[0013] In a second aspect, a method for charging an electric vehicle is provided. The method comprises determining a position of a charging port on the electric vehicle based on an image of the charging port captured by a camera arranged on an end executor of a robot; determining, based on the position of the charging port, a starting position for plugging a charging head arranged on the end executor and configured to match with the charging port into the charging port; causing the end executor to move the charging head towards the starting position; and in response to the charging head reaching the starting position, causing the end executor to move the charging head based on the force condition of the charging head until the plugging of the charging head is completed.

[0014] In some embodiments, causing the end executor to move the charging head based on the force condition of the charging head comprises: in response to the force condition indicating that a lateral force in a direction intersecting with a plugging

direction of the charging head exceeds a first threshold, causing the end executor to move the charging head to reduce the lateral force; and in response to the force condition indicating that a vertical force in a direction opposite to the plugging direction exceeds a second threshold, causing the end executor to stop moving.

[0015] In some embodiments, the method further comprises: causing a range sensor arranged on the end executor to detect a distance between the charging port and the range sensor; and determining the position of the charging port based on the image of the charging port and the detected distance.

[0016] In some embodiments, the range sensor comprises an ultrasonic sensor or a laser sensor.

[0017] In some embodiments, determining the position of the charging port based on the image of the charging port comprises: causing the camera to capture an initial image of the charging port; determining a center point of the charging port in the initial image; causing the camera to capture a plurality of intermediate images of the charging port from different angles around the center point; determining a pose of the charging port based on the plurality of intermediate images; causing the end executor to move based on the pose of the charging port such that an image plane of the camera is parallel to a surface of the charging port; causing the camera to capture a final image of the charging port; and determining the position of the charging port based on the final image.

[0018] In a third aspect, a method for calibrating an apparatus for charging an electric vehicle is provided. The apparatus comprises a charging head arranged on an end executor of a robot and configured to match with a charging port on the electric vehicle, a camera arranged on the end executor and configured to capture an image of the charging port, and a range sensor arranged on the end executor and configured to detect a distance between the charging port and the range sensor. The method comprises: causing the camera to capture a reflection image of the apparatus reflected in a mirror arranged in front of the apparatus, wherein an image plane of the camera is set to be parallel to the mirror; determining a first position relationship between the camera and the charging head based on the captured reflection image; causing the range sensor to detect a distance between the mirror and the range sensor; and determining a second position relationship between the camera and the range

sensor based on the captured reflection image and the distance between the mirror and the range sensor.

[0019] In embodiments of the present disclosure, a mirror is arranged in front of the apparatus to directly determine geometric relations among the camera, the range sensor and the charging head. In this way, the geometric relations among these components can be obtained precisely.

[0020] In some embodiments, the method further comprises: determining a position of the charging head in a coordinate system of the robot based on the first position relationship and a predetermined position relationship between the camera and the end executor; and determining a position of the range sensor in the coordinate system of the robot based on the second position relationship and the predetermined position relationship between the camera and the end executor.

[0021] In some embodiments, the predetermined position relationship between the camera and the end executor is obtained through hand-eye calibration.

DESCRIPTION OF DRAWINGS

[0022] Drawings described herein are provided to further explain the present disclosure and constitute a part of the present disclosure. The example embodiments of the disclosure and the explanation thereof are used to explain the present disclosure, rather than to limit the present disclosure improperly.

[0023] FIG. 1 illustrates a schematic diagram of an electric vehicle and an apparatus for charging the electric vehicle, in accordance with embodiments of the present disclosure;

[0024] FIG. 2 illustrates a schematic diagram of a charging port arranged on the electric vehicle, in accordance with embodiments of the present disclosure;

[0025] FIG. 3 illustrates a schematic diagram of an apparatus for charging the electric vehicle, in accordance with embodiments of the present disclosure;

[0026] FIG. 4 illustrates an initial image of the charging port captured by a camera, in accordance with embodiments of the present disclosure;

[0027] FIGS. 5-7 illustrate intermediate images of the charging port captured by the camera, in accordance with embodiments of the present disclosure;

[0028] FIG. 8 illustrates an final image of the charging port captured by the camera, in accordance with embodiments of the present disclosure;

[0029] FIG. 9 illustrates a flowchart of a method for charging the electric vehicle, in accordance with an embodiment of the present disclosure;

[0030] FIG. 10 illustrates a schematic diagram of a mirror for use in calibrating the apparatus for charging the electric vehicle, in accordance with embodiments of the present disclosure;

[0031] FIG. 11 illustrates a schematic diagram of a calibration pattern for use in a hand-eye calibration process, in accordance with embodiments of the present disclosure;

[0032] FIG. 12 illustrates a reflection image of the apparatus for charging the electric vehicle reflected in the mirror captured by the camera, in accordance with embodiments of the present disclosure; and

[0033] FIG. 13 illustrates a flowchart of a method for calibrating the apparatus for charging the electric vehicle, in accordance with an embodiment of the present disclosure.

[0034] Throughout the drawings, the same or similar reference symbols are used to indicate the same or similar elements.

DETAILED DESCRIPTION OF EMBODIEMTNS

[0035] Principles of the present disclosure will now be described with reference to several example embodiments shown in the drawings. Though example embodiments of the present disclosure are illustrated in the drawings, it is to be understood that the embodiments are described only to facilitate those skilled in the art in better understanding and thereby achieving the present disclosure, rather than to limit the scope of the disclosure in any manner.

[0036] The term “comprises” or “includes” and its variants are to be read as open

terms that mean "includes, but is not limited to." The term "or" is to be read as "and/or" unless the context clearly indicates otherwise. The term "based on" is to be read as "based at least in part on." The term "being operable to" is to mean a function, an action, a motion or a state can be achieved by an operation induced by a user or an external mechanism. The term "one embodiment" and "an embodiment" are to be read as "at least one embodiment." The term "another embodiment" is to be read as "at least one other embodiment." The terms "first," "second," and the like may refer to different or same objects. Other definitions, explicit and implicit, may be included below. A definition of a term is consistent throughout the description unless the context clearly indicates otherwise.

[0037] Unless specified or limited otherwise, the terms "mounted," "connected," "supported," and "coupled" and variations thereof are used broadly and encompass direct and indirect mountings, connections, supports, and couplings. Furthermore, "connected" and "coupled" are not restricted to physical or mechanical connections or couplings. In the description below, like reference numerals and labels are used to describe the same, similar or corresponding parts in the figures. Other definitions, explicit and implicit, may be included below.

[0038] As discussed above, in the conventional EV charging system, the contact forces/torques generated during the plugging process of the charging head into the charging port cannot be predicted and responded fast and accurately; thus, there is a risk that the plugging process may fail and the charging head and the charging port may be damaged during the plugging process. According to embodiments of the present disclosure, the movement of the charging head is controlled based on the force condition of the charging head during the plugging process, so as to avoid the plugging failure and reduce the physical damage to the charging apparatus. The above idea may be implemented in various manners, as will be described in detail in the following paragraphs. Hereinafter, the principles of charging the electric vehicle in the present disclosure will be described in detail with reference to FIGS. 1-9.

[0039] FIG. 1 illustrates a schematic diagram of an electric vehicle 200 and an apparatus 100 for charging the electric vehicle 200, and FIG. 2 illustrates a schematic diagram of a charging port 21 arranged on the electric vehicle 200. The electric vehicle 200 may be of various types, e.g., a battery electric vehicle or a hybrid electric

vehicle. The electric vehicle 200 includes a battery (not shown) for providing electrical power. When the battery is running low, it can be charged by the apparatus 100 via the charging port 21.

[0040] In an embodiment, as shown in Fig. 2, the charging port 21 is provided with a plurality of first connector pins 217. It is to be understood that the number and arrangement of the first connector pins 217 illustrated in Fig. 2 are only used as example for explaining the principles of the present disclosure, rather than to limit the scope of the present disclosure.

[0041] Hereafter, example constitution and operation of the apparatus 100 for charging the electric vehicle 200 will be described with respect to FIGS. 3-9.

[0042] FIG. 3 illustrates a schematic diagram of the apparatus 100 for charging the electric vehicle 200. As shown, the apparatus 100 for charging the electric vehicle 200 generally includes a charging head 11, a camera 12, a force sensor 13, and a controller 14. The charging head 11, the camera 12, the force sensor 13 are arranged on an end executor 300 of a robot.

[0043] The charging head 11 matches with the charging port 21 on the electric vehicle 200. Specifically, the charging head 11 are provided with a plurality of second connector pins 110 to be electrically connected to the first connector pins 217. The number and arrangement of the second connector pins 110 correspond to those of the first connector pins 217. When the electric vehicle 200 is to be charged by the apparatus 100, the charging head 11 may be plugged into the charging port 21, such that each of the second connector pins 110 is electrically connected to the corresponding first connector pin 217.

[0044] The camera 12 is used to capture an image of the charging port 21 so as to be used as a basis for determining the position of the charging port 21 in a coordinate system of the robot. The force sensor 13 is used to detect a force condition of the charging head 11, e.g., contact forces and/or torques. Based on the captured image of the charging port 21 and the detected force condition of the charging head 11, the controller 14 may implement control procedures on the charging head 11 during the plugging process.

[0045] Specifically, the controller 14 first determines the position of the charging

port 21 based on the image of the charging port 21. The determination of the position of the charging port 21 may be implemented in various manners. Hereafter, an example manner for determining the position of the charging port 21 will be described with reference to FIGS. 4-8.

[0046] As shown in FIG. 4, the camera 12 first captures an initial image 210 of the charging port 21 so as to coarsely localize the charging port 21. Since an image plane of the camera 12 may not be parallel to a surface of the charging port 21, the controller 14 generally cannot precisely determine the position of the charging port 21 based on the initial image 210. From the initial image 210, the controller 14 may determine an approximate center point 2101 of the charging port 21. For example, a middle point of a connection line between the centers of two connector pins 217 may be determined as the center point 2101 of the charging port 21.

[0047] The camera 12 then captures a plurality of intermediate images of the charging port 21 from different angles around the center point 2101. FIGS. 5-7 illustrate three intermediate images 211 of the charging port 21 from different angles. It is to be understood that these intermediate images 211 are only used as example for explaining the principles of the present disclosure, rather than to limit the scope of the present disclosure. In other embodiments, the camera 12 may capture more (for example, four, five, or even more) or less (for example, two) intermediate images 211. Since the intermediate images 211 are captured from different angles, the controller 14 may then determine a pose of the charging port 21 based on these intermediate images 211.

[0048] Based on the determined pose of the charging port 21, the controller 14 may then cause the end executor 300 to move such that the image plane of the camera 12 is parallel to the surface of the charging port 21. As shown in FIG. 8, the camera 12 then captures a final image 212 of the charging port 21. Since the image plane of the camera 12 is parallel to the surface of the charging port 21 currently, the controller 14 may determine the position of the charging port 21 based on the final image 212 in a relatively accurate manner.

[0049] Upon obtaining the position of the charging port 21, the controller 14 may determine a starting position for plugging the charging head 11 into the charging port 21. Then, the controller 14 causes the end executor 300 to move the charging head

11 towards the starting position. In response to the charging head 11 reaching the starting position, the controller 14 causes the end executor 300 to move the charging head 11 based on the force condition of the charging head 11 until the plugging of the charging head 11 is completed.

[0050] In embodiments of the present disclosure, the movement of the charging head 11 can be controlled based on its force condition during the plugging process, thereby avoiding the plugging failure and reducing the physical damage to the charging apparatus 100.

[0051] It is to be understood that, in embodiments of the present disclosure, the controller 14 may be a controller of the robot or a separate controller different from the controller of the robot.

[0052] In some embodiments, in response to the force condition indicating that a lateral force in a direction intersecting with a plugging direction X of the charging head 11 exceeds a first threshold, the controller 14 causes the end executor 300 to move the charging head 11 to reduce the lateral force. The first threshold may be set to be a relatively small value such that the controller 14 may respond to a small change of the force condition of the charging head 11. In this way, the charging head 11 may be precisely plugged into the charging port 21 and protected from being damaged.

[0053] In some embodiments, in response to the force condition indicating that a vertical force in a direction opposite to the plugging direction X exceeds a second threshold, the controller 14 causes the end executor 300 to stop moving. At this point, the charging head 11 has been fully plugged into the charging port 21. The second threshold may be set to be a relatively large value such that the end of the plugging process can be determined reliably. In other embodiments, the controller 14 may control the stopping point of the end executor 300 further based on other factors, e.g., an insertion distance of the charging head 11 into the charging port 21 or a control signal indicating that the charging head 11 and the charging port 21 form a good connection. As an example, the controller 14 may cause the end executor 300 to stop moving, in response to the force condition indicating that the vertical force exceeds the second threshold, the insertion distance exceeding a pre-set minimum insertion distance, and the control signal indicating that the charging head 11 and the

charging port 21 form a good connection. In this way, the stopping point of the end executor 300 can be determined more precisely and reliably.

[0054] As discussed above, after the starting position, the controller 14 enters a force control mode in which the movement of the charging head 11 depends on its force condition and the path positional accuracy is no longer guarantied. If the travel distance of the charging head 11 before contacting the charging port 21 is too long, a path position deviation under the force control mode may be too much to form a good initial engagement between the charging head 11 and the charging port 21. Thus, an accurate distance between the charging head 11 and the charging port 21 at the starting position is important for the charging apparatus 100.

[0055] The camera 12 may not be sufficient to accurately determine the distance between the charging head 11 and the charging port 21, because the distance is normal to the image plane of the camera 12.

[0056] To improve the accuracy of determining the distance between the charging head 11 and the charging port 21, a range sensor 15 can be arranged on the end executor 300 to detect the distance between the charging port 21 and the range sensor 15. Then, the controller 14 may determine the position of the charging port 21 based on the image of the charging port 21 and the detected distance. In some embodiments, the range sensor 15 may comprise an ultrasonic sensor or a laser sensor. In other embodiments, the range sensor 15 may be of other types.

[0057] FIG. 9 illustrates a flowchart of a method 900 for charging the electric vehicle 200. The method 900 may be implemented by the apparatus 100 as described above.

[0058] At 910, the apparatus 100 may determine the position of the charging port 21 based on an image of the charging port 21 captured by the camera 12 arranged on the end executor 300 of the robot. As discussed above, the determination of the position of the charging port 21 may be implemented in various manners. An example manner for determining the position of the charging port 21 is described with reference to FIGS. 4-8.

[0059] At 920, the apparatus 100 may determine the starting position for plugging the charging head 11 into the charging port 21 based on the position of the charging

port 21.

[0060] At 930, the apparatus 100 may cause the end executor 300 to move the charging head 11 towards the starting position.

[0061] At 940, in response to the charging head 11 reaching the starting position, the apparatus 100 may cause the end executor 300 to move the charging head 11 based on the force condition of the charging head 11 until the plugging of the charging head 11 is completed.

[0062] In some embodiments, causing the end executor 300 to move the charging head 11 based on the force condition of the charging head 11 includes: in response to the force condition indicating that a lateral force in a direction intersecting with a plugging direction X of the charging head 11 exceeds a first threshold, causing the end executor 300 to move the charging head 11 to reduce the lateral force; and in response to the force condition indicating that a vertical force in a direction opposite to the plugging direction X exceeds a second threshold, causing the end executor 300 to stop moving.

[0063] In some embodiments, the method 900 further includes: causing a range sensor 15 arranged on the end executor 300 to detect a distance between the charging port 21 and the range sensor 15; and determining the position of the charging port 21 based on the image of the charging port 21 and the detected distance.

[0064] In some embodiments, determining the position of the charging port 21 based on the image of the charging port 21 includes: causing the camera 12 to capture an initial image 210 of the charging port 21; determining a center point 2101 of the charging port 21 in the initial image 210; causing the camera 12 to capture a plurality of intermediate images 211 of the charging port 21 from different angles around the center point 2101; determining a pose of the charging port 21 based on the plurality of intermediate images 211; causing the end executor 300 to move based on the pose of the charging port 21 such that an image plane of the camera 12 is parallel to a surface of the charging port 21; causing the camera 12 to capture a final image 212 of the charging port 21; and determining the position of the charging port 21 based on the final image 212.

[0065] Before the apparatus 100 for charging the electric vehicle 200 can be used

normally, it needs to be calibrated so as to determine relative position relationships among the charging head 11, the camera 12 and the range sensor 15. Hereinafter, the principles of calibrating the apparatus 100 for charging the electric vehicle 200 in the present disclosure will be described in detail with reference to FIGS. 10-13.

[0066] FIG. 10 illustrates a schematic diagram of a mirror 40 for use in calibrating the apparatus 100 for charging the electric vehicle 200, FIG. 11 illustrates a schematic diagram of a calibration pattern 800 for use in a hand-eye calibration process, FIG. 12 illustrates a reflection image 1200 of the apparatus 100 reflected in the mirror 40 captured by the camera 12, and FIG. 13 illustrates a flowchart of a method 1300 for calibrating the apparatus 100 for charging the electric vehicle 200.

[0067] As shown in FIG. 10, a mirror 40 is arranged in front of the apparatus 100 at a desired focus distance. The image plane of the camera 12 is set to be parallel to the mirror 40. With such an arrangement, the vision distortion of the camera 12 is minimized.

[0068] As shown in FIG. 11, a calibration pattern 800 with a neglectable thickness may be attached to the mirror 40. This calibration pattern 800 is used for hand-eye calibration and removed afterwards. The hand-eye calibration is a conventional approach for determining a predetermined position relationship between the camera 12 and the end executor 300. Thus, the specific process of the hand-eye calibration would not be described any more herein.

[0069] As shown in Fig. 13, at 1310, the camera 12 is caused to capture a reflection image 1200 (see FIG. 12) of the apparatus 100 reflected in the mirror 40. At 1320, a first position relationship between the camera 12 and the charging head 11 is determined based on the captured reflection image 1200. At 1330, the range sensor 15 is caused to detect a distance between the mirror 40 and the range sensor 15. At 1340, a second position relationship between the camera 12 and the range sensor 15 is determined based on the captured reflection image 1200 and the distance between the mirror 40 and the range sensor 15.

[0070] In some embodiments, the method 1300 further includes determining a position of the charging head 11 in a coordinate system of the robot based on the first position relationship and a predetermined position relationship between the camera 12 and the end executor 300; and determining a position of the range sensor 15 in the

coordinate system of the robot based on the second position relationship and the predetermined position relationship between the camera 12 and the end executor 300. The predetermined position relationship is determined through the hand-eye calibration as described above.

[0071] In embodiments of the present disclosure, the geometric relations among the camera, the range sensor and the charging head may be determined precisely in a direct calibration manner. In this way, the alignment accuracy of the apparatus 100 can be improved.

[0072] While several inventive embodiments have been described and illustrated herein, those of ordinary skill in the art will readily envision a variety of other means and/or structures for performing the function and/or obtaining the results and/or one or more of the advantages described herein, and each of such variations and/or modifications is deemed to be within the scope of the inventive embodiments described herein. More generally, those skilled in the art will readily appreciate that all parameters, dimensions, materials, and configurations described herein are meant to be exemplary and that the actual parameters, dimensions, materials, and/or configurations will depend upon the specific application or applications for which the inventive teachings is/are used. Those skilled in the art will recognize, or be able to ascertain using no more than routine experimentation, many equivalents to the specific inventive embodiments described herein. It is, therefore, to be understood that the foregoing embodiments are presented by way of example only and that, within the scope of the appended claims and equivalents thereto, inventive embodiments may be practiced otherwise than as specifically described and claimed. Inventive embodiments of the present disclosure are directed to each individual feature, system, article, material, kit, and/or method described herein. In addition, any combination of two or more such features, systems, articles, materials, kits, and/or methods, if such features, systems, articles, materials, kits, and/or methods are not mutually inconsistent, is included within the inventive scope of the present disclosure.

WHAT IS CLAIMED IS:

1. An apparatus (100) for charging an electric vehicle (200), comprising:

a charging head (11) arranged on an end executor (300) of a robot and configured to match with a charging port (21) on the electric vehicle (200);

a camera (12) arranged on the end executor (300) and configured to capture an image of the charging port (21);

a force sensor (13) arranged on the end executor (300) and configured to detect a force condition of the charging head (11); and

a controller (14) configured to:

determine a position of the charging port (21) based on the image of the charging port (21);

determine a starting position for plugging the charging head (11) into the charging port (21) based on the position of the charging port (21);

cause the end executor (300) to move the charging head (11) towards the starting position; and

in response to the charging head (11) reaching the starting position, cause the end executor (300) to move the charging head (11) based on the force condition of the charging head (11) until the plugging of the charging head (11) is completed.

2. The apparatus (100) according to claim 1, wherein the controller is configured to cause the end executor (300) to move the charging head (11) based on the force condition of the charging head (11) by:

in response to the force condition indicating that a lateral force in a direction intersecting with a plugging direction (X) of the charging head (11) exceeds a first threshold, causing the end executor (300) to move the charging head (11) to reduce the lateral force; and

in response to the force condition indicating that a vertical force in a direction opposite to the plugging direction (X) exceeds a second threshold, causing the end executor (300) to stop moving.

3. The apparatus (100) according to claim 1, further comprising:

a range sensor (15) arranged on the end executor (300) and configured to detect a distance between the charging port (21) and the range sensor (15),

wherein the controller (14) is further configured to determine the position of the charging port (21) based on the image of the charging port (21) and the detected distance.

4. The apparatus (100) according to claim 3, wherein the range sensor (15) comprises an ultrasonic sensor or a laser sensor.

5. The apparatus (100) according to claim 1, wherein the controller (14) is configured to determine the position of the charging port (21) based on the image of the charging port (21) by:

causing the camera (12) to capture an initial image (210) of the charging port (21);

determining a center point (2101) of the charging port (21) in the initial image (210);

causing the camera (12) to capture a plurality of intermediate images (211) of the charging port (21) from different angles around the center point (2101);

determining a pose of the charging port (21) based on the plurality of intermediate images (211);

causing the end executor (300) to move based on the pose of the charging port (21) such that an image plane of the camera (12) is parallel to a surface of the charging port (21);

causing the camera (12) to capture a final image (212) of the charging port (21); and

determining the position of the charging port (21) based on the final image (212).

6. A method for charging an electric vehicle (200), comprising:

determining a position of a charging port (21) on the electric vehicle (200) based on an image of the charging port (21) captured by a camera (12) arranged on an end executor (300) of a robot;

determining, based on the position of the charging port (21), a starting position for plugging a charging head (11) arranged on the end executor (300) and configured to match with the charging port (21) into the charging port (21);

causing the end executor (300) to move the charging head (11) towards the starting position; and

in response to the charging head (11) reaching the starting position, causing the end executor (300) to move the charging head (11) based on the force condition of the charging head (11) until the plugging of the charging head (11) is completed.

7. The method according to claim 6, wherein causing the end executor (300) to move the charging head (11) based on the force condition of the charging head (11) comprises:

in response to the force condition indicating that a lateral force in a direction intersecting with a plugging direction (X) of the charging head (11) exceeds a first threshold, causing the end executor (300) to move the charging head (11) to reduce the lateral force; and

in response to the force condition indicating that a vertical force in a direction opposite to the plugging direction (X) exceeds a second threshold, causing the end executor (300) to stop moving.

8. The method according to claim 6, further comprising:

causing a range sensor (15) arranged on the end executor (300) to detect a distance between the charging port (21) and the range sensor (15); and

determining the position of the charging port (21) based on the image of the charging port (21) and the detected distance.

9. The method according to claim 8, wherein the range sensor (15) comprises an ultrasonic sensor or a laser sensor.

10. The method according to claim 6, wherein determining the position of the charging port (21) based on the image of the charging port (21) comprises:

causing the camera (12) to capture an initial image (210) of the charging port (21);

determining a center point (2101) of the charging port (21) in the initial image (210);

causing the camera (12) to capture a plurality of intermediate images (211) of the charging port (21) from different angles around the center point (2101);

determining a pose of the charging port (21) based on the plurality of intermediate images (211);

causing the end executor (300) to move based on the pose of the charging port (21) such that an image plane of the camera (12) is parallel to a surface of the charging port (21);

causing the camera (12) to capture a final image (212) of the charging port (21); and

determining the position of the charging port (21) based on the final image (212).

11. A method for calibrating an apparatus (100) for charging an electric vehicle (200), the apparatus (100) comprising a charging head (11) arranged on an end executor (300) of a robot and configured to match with a charging port (21) on the electric vehicle (200), a camera (12) arranged on the end executor (300) and configured to capture an image of the charging port (21), and a range sensor (15) arranged on the end executor (300) and configured to detect a distance between the charging port (21) and the range sensor (15), the method comprising:

causing the camera (12) to capture a reflection image (1200) of the apparatus (100) reflected in a mirror (40) arranged in front of the apparatus (100), wherein an image plane of the camera (12) is set to be parallel to the mirror (40);

determining a first position relationship between the camera (12) and the charging head (11) based on the captured reflection image (1200);

causing the range sensor (15) to detect a distance between the mirror (40) and the range sensor (15); and

determining a second position relationship between the camera (12) and the range sensor (15) based on the captured reflection image (1200) and the distance between the mirror (40) and the range sensor (15).

12. The method according to claim 11, further comprising:

determining a position of the charging head (11) in a coordinate system of the robot based on the first position relationship and a predetermined position relationship between the camera (12) and the end executor (300); and

determining a position of the range sensor (15) in the coordinate system of the robot based on the second position relationship and the predetermined position relationship between the camera (12) and the end executor (300).

13. The method according to claim 12, wherein the predetermined position relationship between the camera (12) and the end executor (300) is obtained through

hand-eye calibration.

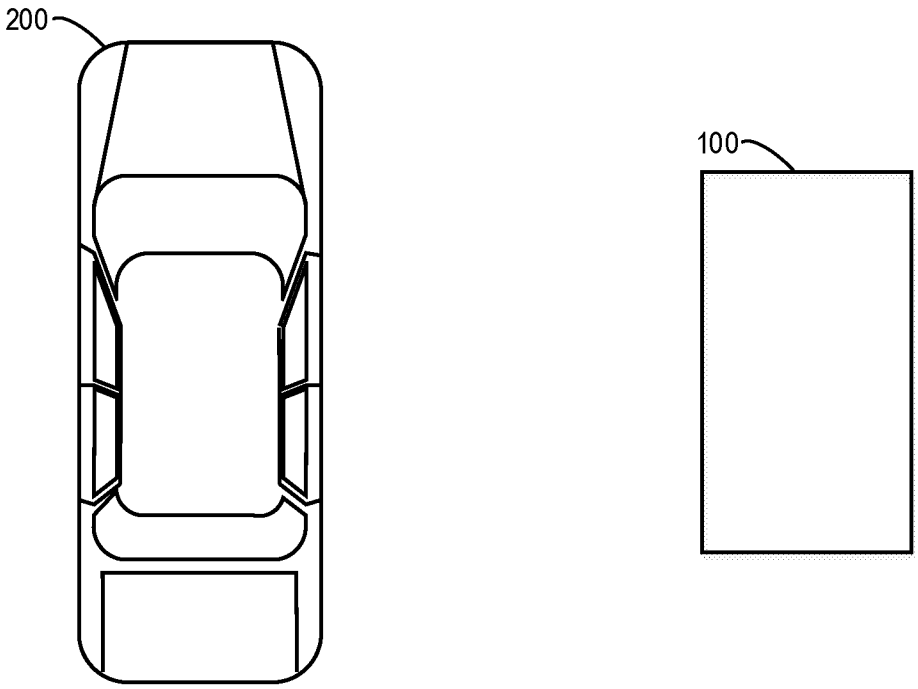


FIG. 1

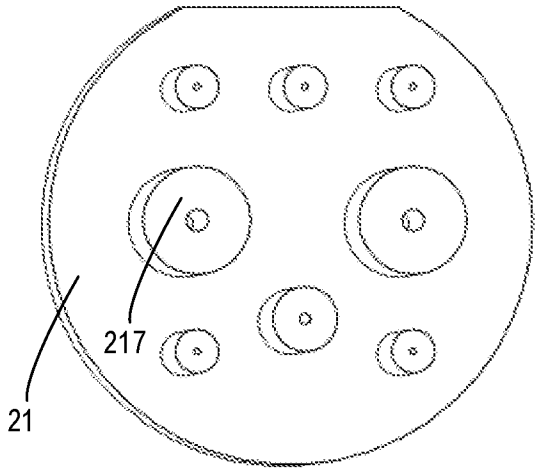


FIG. 2

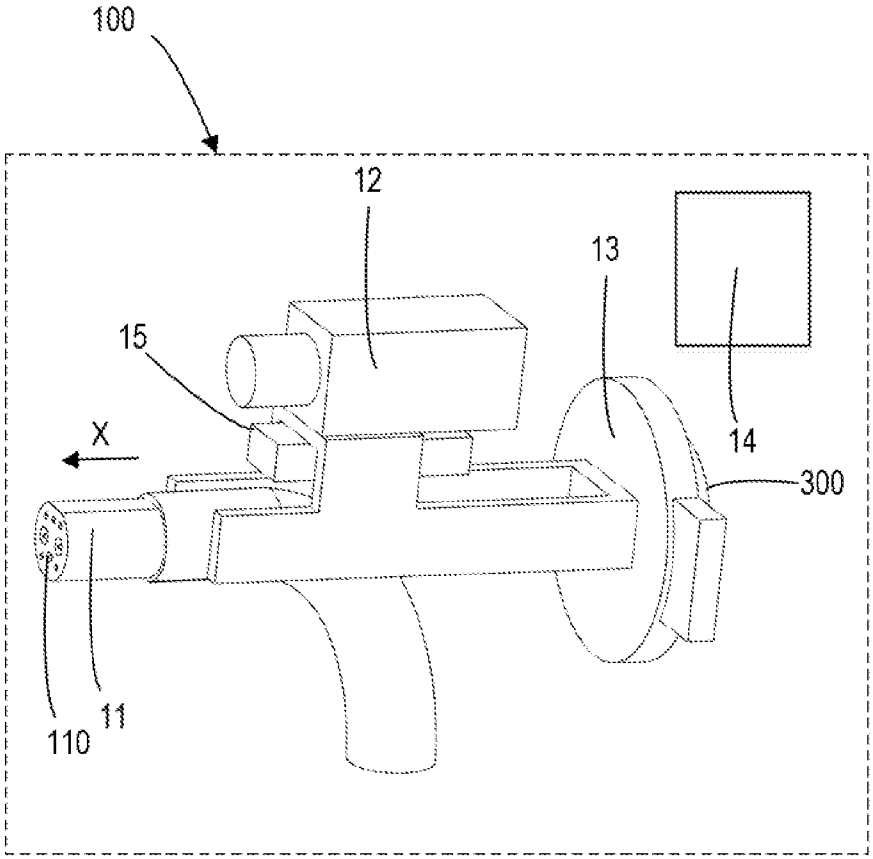


FIG. 3

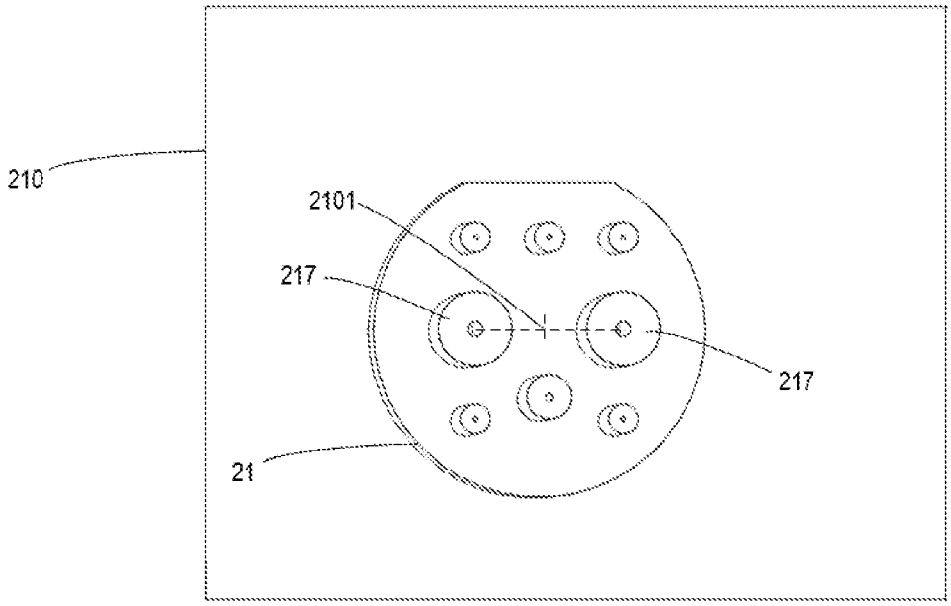


FIG. 4

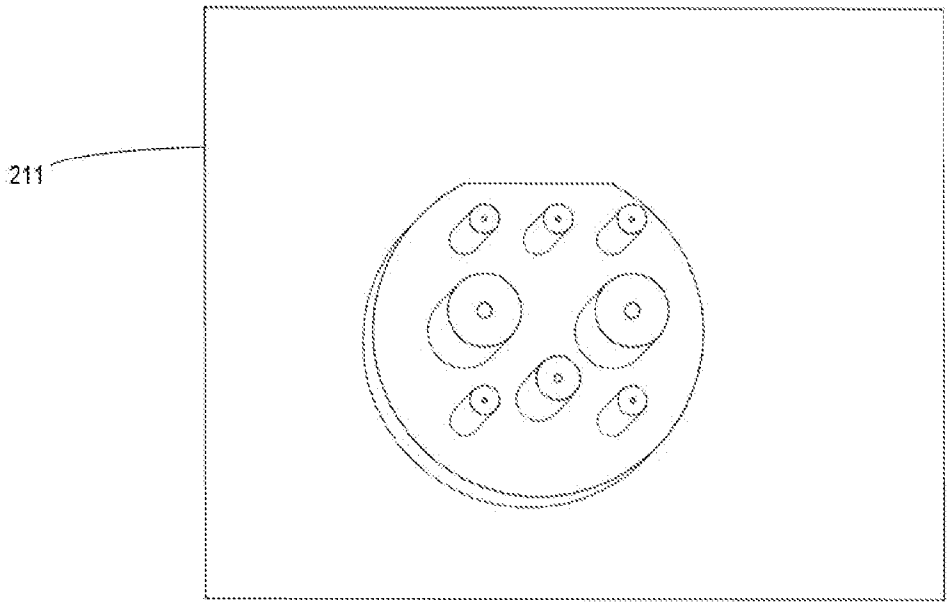


FIG. 5

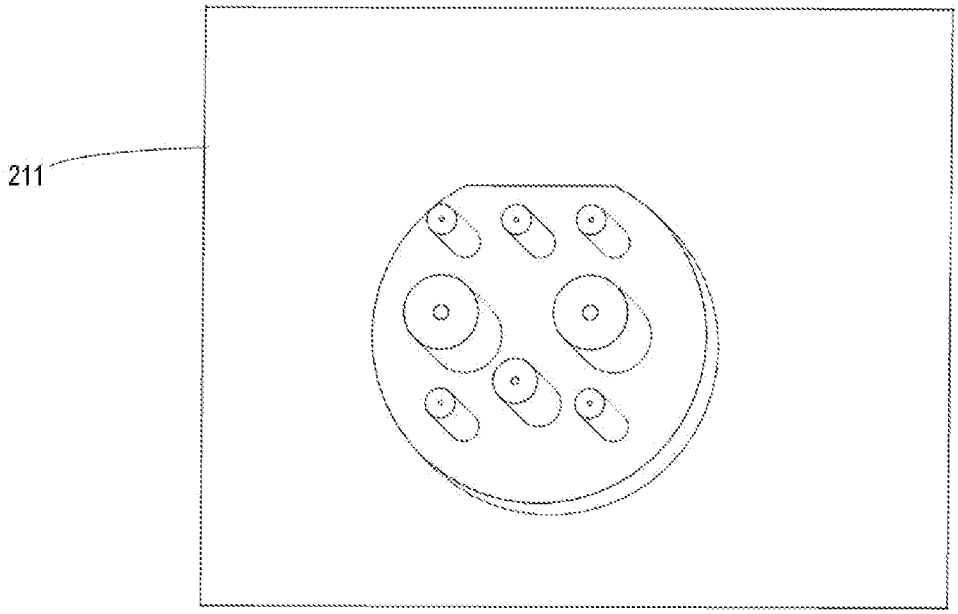


FIG. 6

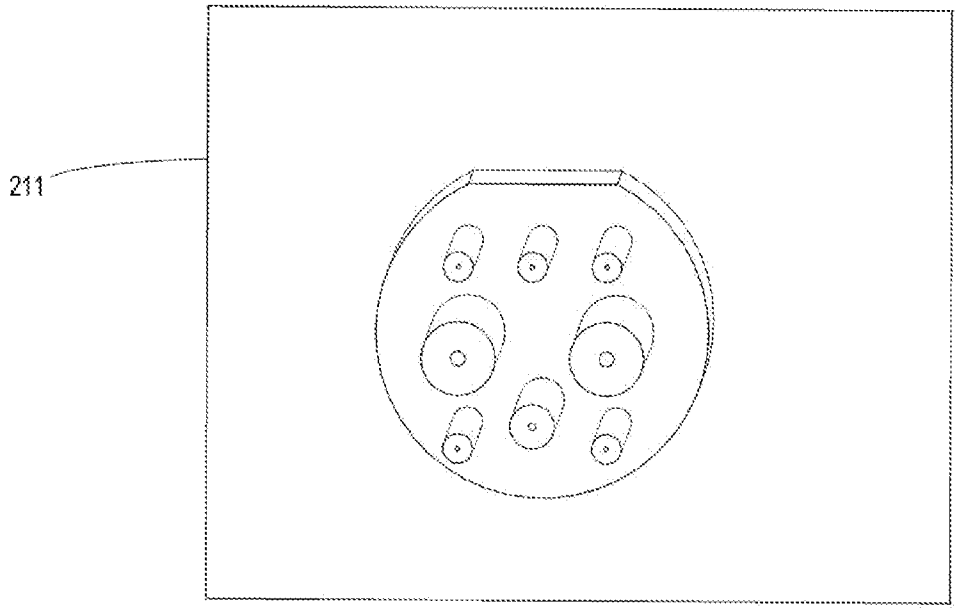


FIG. 7

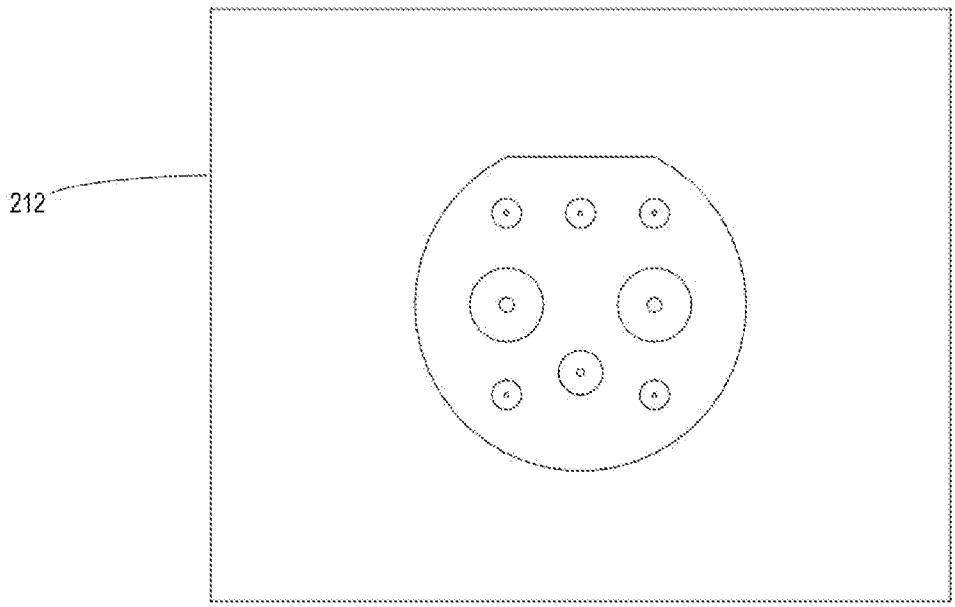


FIG. 8

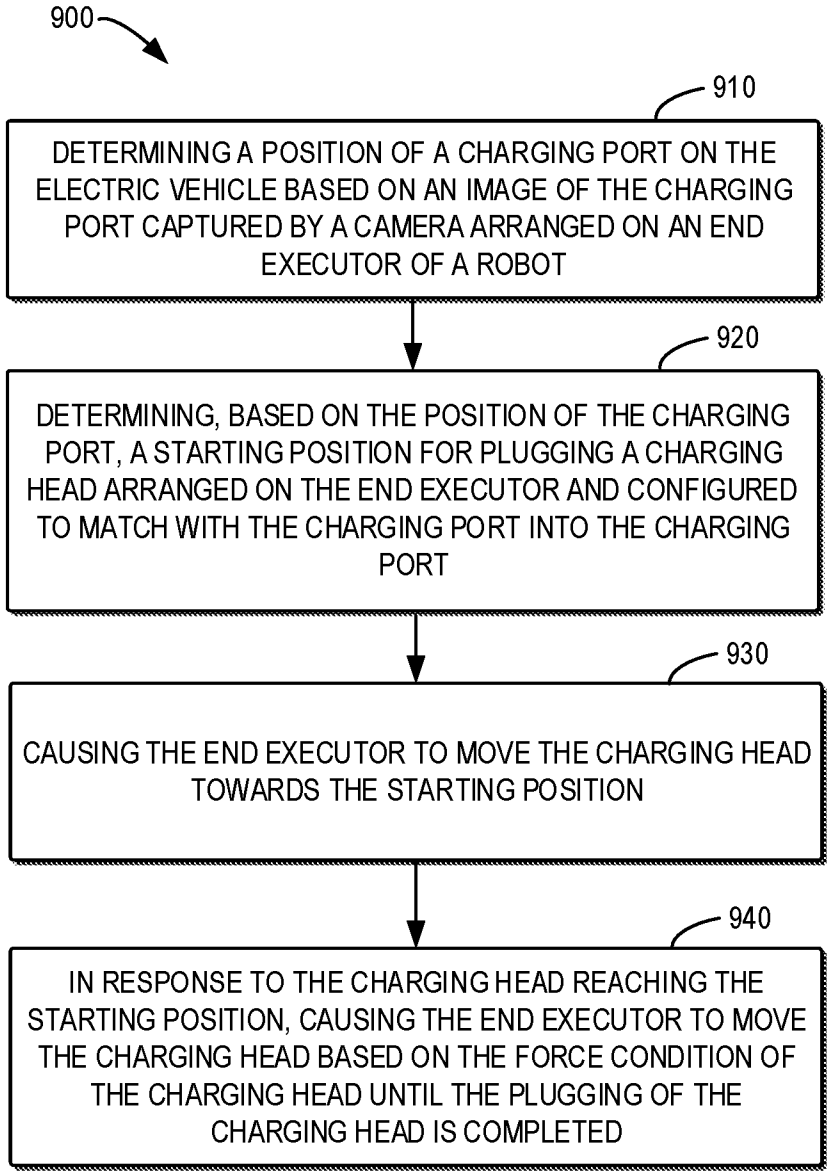

900
910
DETERMINING A POSITION OF A CHARGING PORT ON THE ELECTRIC VEHICLE BASED ON AN IMAGE OF THE CHARGING PORT CAPTURED BY A CAMERA ARRANGED ON AN END EXECUTOR OF A ROBOT
920
DETERMINING, BASED ON THE POSITION OF THE CHARGING PORT, A STARTING POSITION FOR PLUGGING A CHARGING HEAD ARRANGED ON THE END EXECUTOR AND CONFIGURED TO MATCH WITH THE CHARGING PORT INTO THE CHARGING PORT
930
CAUSING THE END EXECUTOR TO MOVE THE CHARGING HEAD TOWARDS THE STARTING POSITION
940
IN RESPONSE TO THE CHARGING HEAD REACHING THE STARTING POSITION, CAUSING THE END EXECUTOR TO MOVE THE CHARGING HEAD BASED ON THE FORCE CONDITION OF THE CHARGING HEAD UNTIL THE PLUGGING OF THE CHARGING HEAD IS COMPLETED

FIG. 9

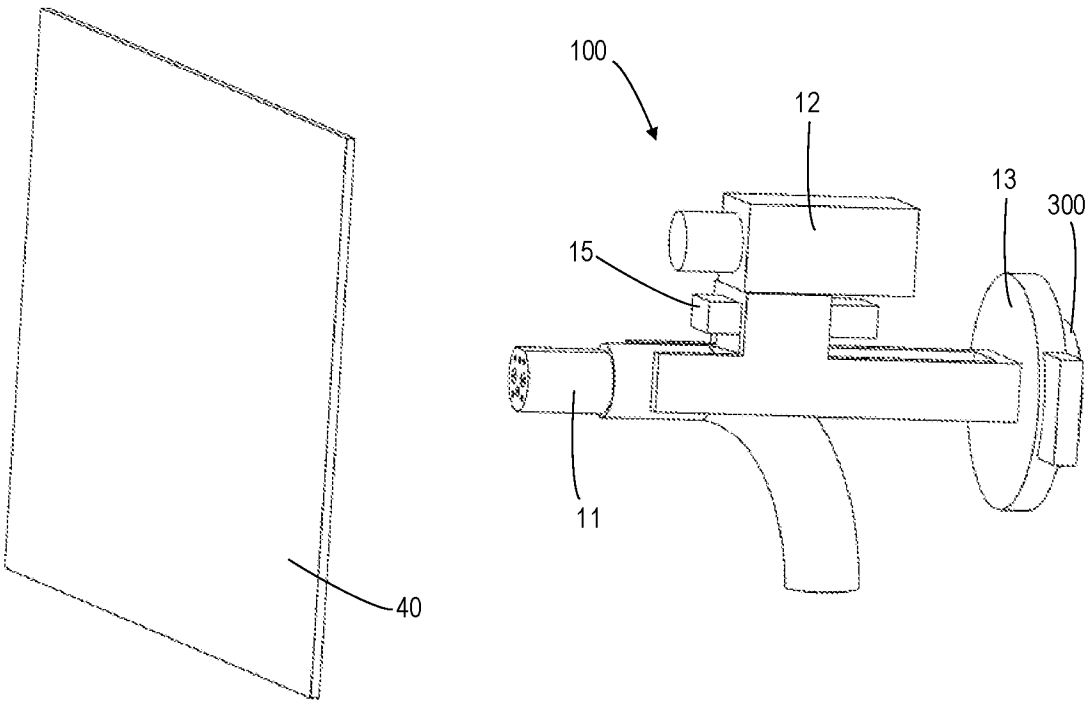


FIG. 10

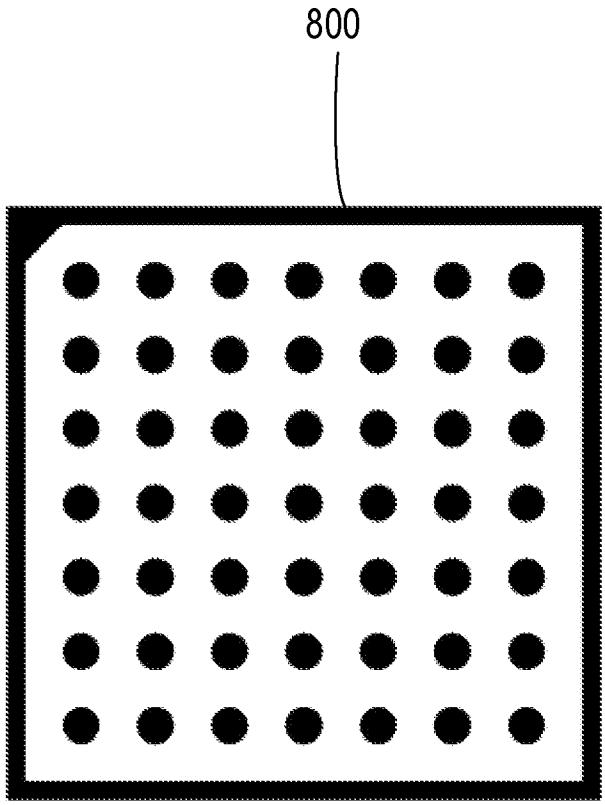


FIG. 11

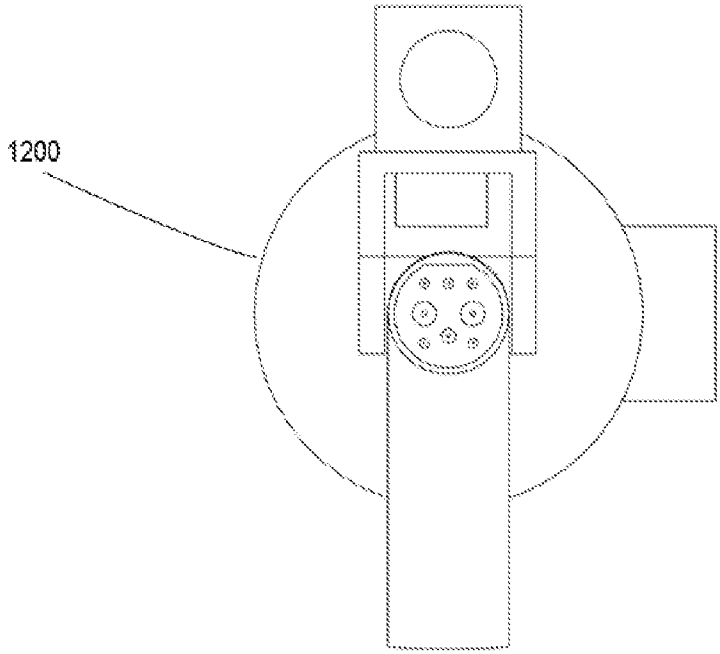


FIG. 12

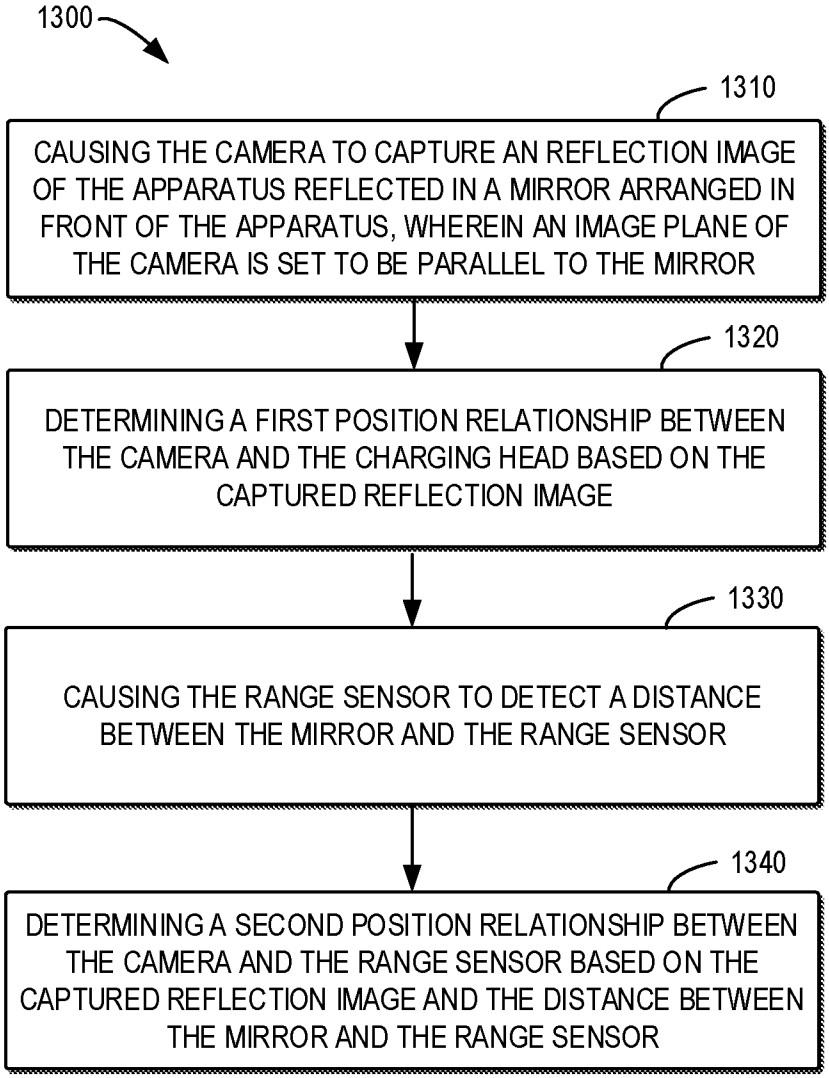

1300
1310
CAUSING THE CAMERA TO CAPTURE AN REFLECTION IMAGE OF THE APPARATUS REFLECTED IN A MIRROR ARRANGED IN FRONT OF THE APPARATUS, WHEREIN AN IMAGE PLANE OF THE CAMERA IS SET TO BE PARALLEL TO THE MIRROR
1320
DETERMINING A FIRST POSITION RELATIONSHIP BETWEEN THE CAMERA AND THE CHARGING HEAD BASED ON THE CAPTURED REFLECTION IMAGE
1330
CAUSING THE RANGE SENSOR TO DETECT A DISTANCE BETWEEN THE MIRROR AND THE RANGE SENSOR
1340
DETERMINING A SECOND POSITION RELATIONSHIP BETWEEN THE CAMERA AND THE RANGE SENSOR BASED ON THE CAPTURED REFLECTION IMAGE AND THE DISTANCE BETWEEN THE MIRROR AND THE RANGE SENSOR

FIG. 13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2019/089579

A. CLASSIFICATION OF SUBJECT MATTER

B60L 53/37(2019.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B60L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI,EPODOC,CNPAT,CNKI:robot,charge,calibrating,vehicle,camera,force,sensor,plug,direction,mirror, range

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 104520134 A (KUKA ROBOTER GMBH) 15 April 2015 (2015-04-15) paragraphs [0010]-[0046] , figure1	1-10
Y	CN 104520134 A (KUKA ROBOTER GMBH) 15 April 2015 (2015-04-15) paragraphs [0010]-[0046] , figure1	11-13
Y	CN 102889879 A (AXIS AB) 23 January 2013 (2013-01-23) paragraphs[0036]-[0059], figures 1-7	11-13
A	DE 102015213161 A1 (VOLKSWAGEN AG) 19 January 2017 (2017-01-19) the whole document	1-13
A	CN 108556664 A (GUANGZHOU DREAM ONE ROBOT AUTOMATION CO.) 21 September 2018 (2018-09-21) the whole document	1-13

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 February 2020	**25 February 2020**

Name and mailing address of the ISA/CN	Authorized officer
National Intellectual Property Administration, PRC **6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088** **China**	**YAN,Chao**
Facsimile No. **(86-10)62019451**	Telephone No. **86-(10)-53961504**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2019/089579

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				EP	2877365	A2	03 June 2015
				CN	104520134	B	18 January 2019
				WO	2014015991	A3	12 June 2014
				WO	2014015991	A2	30 January 2014
				US	2015210174	A1	30 July 2015
CN	102889879	A	23 January 2013	TW	I510770	B	01 December 2015
				KR	101578496	B1	18 December 2015
				JP	2013029494	A	07 February 2013
				CN	102889879	B	16 December 2015
				US	8848198	B2	30 September 2014
				US	2013021617	A1	24 January 2013
				EP	2549227	A1	23 January 2013
				JP	5559840	B2	23 July 2014
				TW	201305546	A	01 February 2013
				KR	20130011917	A	30 January 2013
				EP	2549227	B1	11 September 2013
DE	102015213161	A1	19 January 2017	CN	206171211	U	17 May 2017
				DE	102015213161	B4	16 May 2019
CN	108556664	A	21 September 2018	None			