

METHOD FOR CONTROLLING A SYSTEM FOR THE AUTONOMOUS CHARGING OF AN ELECTRIC VEHICLE.

The present invention relates to a method for controlling a system for the autonomous charging of an electric vehicle. The invention is also related to a system for the autonomous charging of an electric vehicle.

The method generally comprises guiding a connector assembly towards a vehicle charging port by actuation of a robotic arm; allowing the robotic arm to transition from an unlocked state to a locked state; effecting the mating of the connector with the charging port by moving the connector assembly while monitoring and analysing operational and/or sensor data; and initiating a corrective action if analysis of the operational and/or sensor data indicates that corrective action is needed to allow the system to complete the mating of the connector with the charging port.

The system for autonomously charging an electric vehicle of the present invention comprises a base unit, a connector assembly to support a connector for mating with a vehicle charging port, a robotic arm positioned between the base unit and the connector assembly, the robotic arm comprising a plurality of arm segments, and control system configured to receive operational and/or sensor data and to guide the robotic arm and connector assembly towards the vehicle charging port.

The system further comprises a control system to control the motion and positioning of the robotic arm based on operational and/or sensor data.

Technical Field

The present invention generally relates to methods for controlling a robotic system to autonomously charge electric vehicles, and related systems.

Background Of The Invention

As electric vehicle adoption rises, the demand for autonomous charging solutions, or autonomous charging devices (ACDs), has increased significantly. These systems use robotic arms with multiple segments connected by joints, offering the flexibility to navigate the spatial complexities of EV charging. The robotic arm's goal is to position and align the charging connector with the EV's charging port, for a reliable connection without human intervention.

Devices and related methods for this purpose are known in the art, for instance from the international patent applications PCT/NL2020/050266, PCT/NL2021/050115, PCT/NL2021/050410, PCT/NL2021/050495, PCT/NL2021/05061, PCT/EP2022/062233, and PCT/EP2022/088101, from the same applicant, all of which are herein incorporated
5 by reference.

Self-driving electric vehicles represent a major leap in the automotive industry, operating without human input. They can independently perform tasks like finding parking, navigating tight spaces, and seeking charging stations. Robotic EV charging systems complement these capabilities by providing seamless, automated charging. As these vehicles advance,
10 a reliable infrastructure, including automated charging, is essential.

Robotic systems for EV charging can also improve at-home charging, not just public stations or self-driving vehicles. However, adapting these systems for home use requires balancing reliability and affordability. Automated home charging provides convenience and efficiency, but designing cost-effective solutions for smaller, cost-sensitive residential
15 environments poses unique challenges.

Furthermore, the integration of robotic systems to facilitate electric vehicle (EV) charging holds significant potential for large fleets of industrial and delivery vehicles. These fleets, typically consisting of vehicles with similar configurations and charging requirements, offer an ideal scenario for scaling up automated charging systems with standardized needs.
20 When a fleet of vehicles shares similar charging port locations and connector designs, establishing a consistent robotic charging infrastructure becomes more achievable.

It is desirable to develop flexible and customizable autonomous charging solutions that can serve as a platform for implementation in different use cases. For instance, some scenarios may necessitate a high degree of automation with minimal human intervention,
25 while others may require more manual control for specialized tasks. The ability to adjust the system's configuration and capabilities to meet these diverse needs may help improve its versatility and applicability across a wide range of applications

It is desirable to provide a cost-efficient autonomous charging system capable of accommodating the variables inherent in the charging process without relying on
30 sophisticated components. It is desirable that such a system be able to manage differences in EV positioning, charging port placements, and various connector designs. Furthermore, it is desirable to provide a system that can cope with real-time changes,

including unexpected movements of the EV, shifts in environmental conditions, and the potential presence of obstructions.

The present invention aims to provide a method and system that addresses many of the challenges described herein.

5 Summary of the Invention

10 In a first embodiment, a method for controlling a robotic system for autonomously charging an electric vehicle is disclosed, the method comprising: guiding a connector assembly towards a vehicle charging port by actuation of a robotic arm; allowing the robotic arm to transition between an unlocked state to a locked state before mating the connector with the charging port based on operational and/or sensor data, wherein in the locked state, at least one arm segment is prevented from undergoing a movement; and wherein in the unlocked state such movement is allowed; effecting the mating of the connector with the charging port by moving the connector assembly while monitoring and analysing such operational and/or sensor data; and initiating a corrective action when such correction is needed.

15 According to an exemplary embodiment, the method comprises comparing the operational and/or sensor data with at least one predetermined operational and/or sensor data and using a result of the comparison to determine whether a corrective action is needed.

20 According to an exemplary embodiment, the method comprises allowing the robotic arm to transition between the unlocked state and locked state when such operational or sensor data is within a predetermined range.

25 According to an exemplary embodiment, the method comprises carrying out at least one of the following actions such that the system is able to complete mating of the connector with the charging port: i) transitioning the robotic arm to the unlocked stage; ii) transitioning the robotic arm to the locked stage; iii) repositioning the robotic arm; or iv) obtaining new, or updated operational or sensor data; or v) reattempting the mating

30 According to an exemplary embodiment, the method comprises receiving: sensor data associated to at least one of: a pose of the charging port, a pose of the connector assembly, a distance between the connector and the charging port, a physical or electric connection between the electric vehicle connector and the charging port, an external force applied to robotic arm, and a physical deflection of a component of the system; and/or

operational data associated to at least one of a signal from the vehicle, an instruction from an operator, or a signal from a remote system.

According to an exemplary embodiment, the method comprises receiving pose data of the charging port or the connector assembly and allowing the robotic arm to transition from the unlocked state to the locked state when such pose data is within a predetermined threshold for mating

According to an exemplary embodiment, during the locked state, at least two arm segments are prevented from undergoing a movement and at one arm segment is allowed to undergoing a movement, in each case with respect to an adjacent arm segment or the base unit.

According to an exemplary embodiment, the method comprises allowing the robotic arm to undergo more than one transition between locked and unlocked states prior to the mating.

According to an exemplary embodiment, the method comprises receiving sensor data associated to an external force acting on the connector and initiating a corrective action when such sensor data deviates from a predetermined range, and wherein such threshold is dependent on the position of the connector in relation to the charging port.

According to an exemplary embodiment, the method comprises allowing the transition of the robotic arm between a stowed position and a deployed position; wherein during the stowed position, the connector assembly, and preferably the charging connector is at least partially engaged by a connector housing, and during the deployed position the connector or connector assembly is not engaged by the connector housing.

According to an exemplary embodiment, the method comprises mating the connector with the charging port during the locked state by allowing the robotic arm to apply a temporarily higher force than a force applied while the robotic arm is in an unlocked state.

According to an exemplary embodiment, the method comprises allowing the transition of the robotic arm from a locked state to an unlocked state at any moment after the mating of the charging connector with the charging port. This may be beneficial as it can allow, for example, the system to adapt to any movements or adjustments made by the electric vehicle (EV) during the charging process, and to reduce the need for a constant energy supply to keep the robotic arm in a locked position.

According to an exemplary embodiment, the method comprises allowing the transition of the robotic arm into a locked state prior to the unmating. This may be facilitate such unmating step. Furthermore, once the connector has been unmated, the robotic arm can be transitioned back into the unlocked state. This transition to the unlocked state can serve multiple purposes, including stowing the robotic arm safely or preparing it for the initiation of another mating cycle, as needed.

According to a second embodiment, a system for autonomously charging an electric vehicle is disclosed, comprising: a base unit; connector assembly to support a connector for mating with a vehicle charging port; a robotic arm positioned between the base unit and connector assembly and comprising a plurality of arm segments. In particular, the robotic arm is configured to transition between an unlocked state and a locked state before mating the connector with the charging port based on the received operational and/or sensor data, wherein in the locked state, at least one arm segment is prevented from undergoing a movement with respect to an adjacent arm segment or base unit; and wherein in the unlocked state such movement is allowed. Furthermore, the control system is configured for monitoring and analysing such operational and/or sensor data and initiating a corrective action if the analysis of the operational and/or sensor data indicates that corrective action is needed to allow the system to complete the mating of the connector with the charging port

In an exemplary embodiment, the system comprises a plurality of joint assemblies configured to move between a first and a second position and thereby adjusting the position of the connector assembly relative to the base unit

In an exemplary embodiment, the at least one joint assembly is configured to enable a rotational, pivoting and/or linear movement between at least one of the connector assembly and an arm segment; between two adjacent arm segments, or between an arm segment and the base unit.

In an exemplary embodiment, the at least one joint assembly comprises an actuator member mounted on an arm segment and a joint section coupled to the actuator member via a transmission assembly.

In an exemplary embodiment, the system comprises one or more sensors configured to generate sensor data and means to receive operational data.

In an exemplary embodiment, at least one of the base unit and arm segments comprise a connector housing defining a geometrical volume for at least partially housing the

connector assembly, and preferably the charging connector. The robotic arm is configured to transition between a stowed position wherein the connector assembly is at least partially engaged by the connector housing, and a deployed position wherein the connector assembly is disengaged from the connector housing

- 5 In an exemplary embodiment at least one of the base unit and arm segments comprise a connector housing defining a geometrical volume for at least partially housing the connector assembly, and preferably the charging connector.

- 10 In an exemplary embodiment the robotic arm is configured to transition between a stowed position wherein the connector assembly is at least partially engaged by the connector housing, and a deployed position wherein the connector assembly is disengaged from the connector housing.

- 15 In an exemplary embodiment at least one joint assembly comprises a joint member and a braking member and the control system is configured to activate and deactivate such braking member to transition the robotic arm between the locked state and unlocked state, and vice versa.

In an exemplary embodiment the control system is configured to receiving pose data of the charging port or connector assembly and allowing the robotic arm to transition from the unlocked state to the locked state when such pose data is within a predetermined threshold for mating.

- 20 In an exemplary embodiment the control system is configured to receive receiving sensor data associated to an external force acting on the connector and initiating a corrective action when such sensor data deviates from a predetermined range, and wherein such threshold is dependent on the position of the connector assembly in relation to the charging port.

- 25 In an exemplary embodiment the control system is configured to limit a velocity of at least one system component when the robotic arm is in the deployed position.

In an exemplary embodiment the control system is configured for mating the connector with the charging port if a distance between the connector and the charging port is lower than or equal to a predetermined threshold.

- 30 In an exemplary embodiment, the control system may selectively lock and unlock individual joint assemblies and subsequently, individual arm segments within the robotic arm to allow, for example, corrections to the position of the robotic arm or the connector

assembly during the charging cycle. By operating in this manner, certain situations where minor misalignments, shifts, or external forces are detected, the control system can trigger the locking and unlocking of individual joint assemblies to make small, localized corrections to the arm's position or the orientation of the connector assembly.

5 In an exemplary embodiment, the control system may activate the locking mechanism in response to input received from at least one sensor or in response to predetermined instructions. In some cases, control system utilizes sensors positioned within, or in communication with, the system to obtain sensor data or to obtain operational parameters, environmental conditions, or external factors. Upon processing sensor data and identifying
10 specific conditions or scenarios where certain stability, precision, or safety is needed, the control system is configured to trigger the transition of one stage to another one, as the case may be.

In an exemplary embodiment, the control system may be configured to trigger a short-term partial locking of the joint assemblies to effectively reduce any momentum that the robotic
15 arm may be subject to, especially in situations where it is rapidly pivoting or undergoing sudden movements.

In an exemplary embodiment, a safety system may be integrated to provide emergency shutdown capabilities and/or deactivate energy supply to the system or to any system component, such as the brake components. Upon activation of such safety system, the
20 robotic arm can be swiftly transitioned from a locked to an unlocked state.

Brief Description of the Drawings

FIG. 1 is a schematized method according to an embodiment of the invention

FIG. 2 is a schematized system according to an embodiment of the invention including a base unit **20**, robotic arm **40**, control system **60** and connector assembly **30**.

25 **FIG. 3** is a schematized system according to an embodiment of the invention including a base unit **20**, robotic arm **40**, a connector housing **70** and connector assembly.

FIG. 4 is a schematized system according to an embodiment of the invention including a base unit **20**, robotic arm **40**, a connector housing **70** and connector assembly **30**. The robotic arm **40** is able to be displaced vertically along the z-axis.

30 **FIG. 5a** and **FIG. 5b** depict two realizations according to the invention, wherein the robotic arm is in a stowed position and deployed position, respectively.

FIG. 6 is a schematized system according to an embodiment of the invention including a base unit 20, a robotic arm 40 having to arm segments 42, 44 coupled to the base unit 20.

FIG. 7 is a schematized system according to an embodiment of the invention including a connector changer 90.

5 FIG. 8a depicts realizations of the invention wherein the system comprises cable support means 110, 111 and FIG. 8b shows a realization where the system comprises a supporting arm 113.

10 FIG. 9a and FIG. 9b depict a schematized system according to an embodiment of the invention including a base unit 20, robotic arm, a compliance assembly 100, a connector housing 70 and connector assembly 30.

FIG. 10a and FIG. 10b depict a schematized system according to an embodiment of the invention including a base unit 20, and robotic arm 40 which is able to displaced vertically along the z-axis.

15 FIG. 11 depicts a schematized system according to an embodiment of the invention including a base unit 20, robotic arm 40, wherein the base unit is able to displaced horizontally along the x-axis.

FIG. 12 is a schematized system according to an embodiment of the invention including wherein the robotic arm 40 is in a stowed position and wherein the connector assembly is engaged by a connector housing 70.

20 FIG. 13a and FIG. 13b depict enlarged views of a connector housing in accordance with several embodiments of the invention.

FIG. 14a and FIG. 14b depict enlarged views of arm segments in accordance with several embodiments of the invention.

25 FIG. 15a and FIG. 15b are schematized depiction of systems 10 in accordance with embodiments of the invention.

Brief Description of the Prior Art

Some existing systems have various shortcomings relative to certain applications. Accordingly, there remains a need for further contributions in this area of technology.

WO2019219339A1 describes a charger robot for a motor vehicle, a method, a device and a computer-readable storage medium with instruction for controlling a charger robot. The charger robot has a robot structure formed by two or more structural elements, as well as a plug receiver for a charging plug. Self-locking drives permit a movement of the plug receiver relative to a charging plug socket of the motor vehicle. A sensor system detects a force exerted on the plug receiver or the charging plug. A control device controls the charger robot in response to a force exerted on the plug receiver or the charging plug detected by the sensor system. This document does not describe a system or method in accordance with the embodiments of the present invention, but instead, focuses on a non-self-locking design, so that after the plug is inserted into the vehicle and the charging robot is connected to the plug, the robot's drives are de-energized. Consequently, when lowering the vehicle, the charging robot also descends.

Detailed Description of the Invention

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which currently preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided for thoroughness and completeness, and fully convey the scope of the invention to the skilled person.

FIG. 1 is a flowchart of a method for controlling a system for the autonomous charging of an electric vehicle in accordance with the present disclosure. The method comprises, among other steps, allowing the robotic arm to transition from an unlocked state to a locked state before mating the connector with the charging port based on the received operational and/or sensor data. By transitioning to a locked state before connecting the charging connector to the electric vehicle's charging port, the control system allows maintaining a predetermined arm configuration, preventing misalignment. Furthermore, locking the arm's segments in place during deployment facilitates orientation for improved connection and charging cycle, reducing the overall force exerted by system components. This transition between one stage to another one can further allow the system to use camera sensors to gather pose information of the charging port, moving thus throughout the workspace of the arm. In the locked state, actuators at the arm's distal end can be activated for mating, aligning the charging connector with the vehicle's port, while the remaining joints and segments can remain locked, reducing resistance and force during the mating process.

FIG. 2 to FIG. 15 depict exemplary embodiments of a system 10 for autonomously charging an electric vehicle in accordance with the present invention, comprising a base unit 20; a connector assembly 30 configured to support an electric vehicle connector 31; a robotic arm 40 positioned between the base unit 20 and the connector assembly 30 and comprising a plurality of arm segments 41 and a plurality of joint assemblies 50, and a control system 60 configured to control the motion and positioning of the robotic arm 40, connector assembly 30 and other components of the system.

In reference to FIG. 2, the robotic arm is preferably a multiple-joint controllable arm which allows such connector assembly 30 to achieve a desired position and orientation. Suitable robotic arms comprise, but are not limited to, six-axis robotic arm systems, Selective Compliant Articulated Robot Arm (SCARA) systems, parallel robotic arms, cartesian robotic arms, delta robotic arms, articulated robotic arms, industrial robotic arms, Steward platforms, hexapod platforms, among others, wherein the degrees of freedom of the connector assembly can be dependent on the robotic arm kinematics, the number of arm links, the number and type of joint assemblies and combinations thereof.

In reference to FIG. 2, factors which can influence the degrees of freedom of the robotic arm 40 and/or connector assembly 30 comprise the combination of number of arm segments 41, the number and type of joint assemblies 50 incorporated in such arm and their spatial disposition. Arm segments may be of any size and shape, but their form usually depends on factors such as: expected degrees of freedom, use case, type of vehicle, type of connector, connector cable weight, load-bearing capacity, manoeuvrability, alignment precision, and adaptability to the electric vehicle charging environment among others.

In reference to any of FIG. 2 to FIG. 15, the system comprises a base unit 20 which is generally configured to support other components of the system 10, which can include at least one of a robotic arm 40, control system 60, connector housing 70 and connector cable 80, among others. FIG. 2 depicts the base unit 20 configured to directly or indirectly support the robotic arm 40 and the movements associated with such robotic arm 40 and connector assembly 30. The base unit 20 may be mechanically structured to support the weight and movement of the robotic arm. The base unit 20 may advantageously comprise stabilization means configured to immobilize the base relative to the ground and at least partially support the weight of the base and the robotic arm (not shown). For example, the base unit 20 may be coupled to a fixed structure such as a wall, floor, or ceiling. Alternatively, the base unit 20 may have a mass and a geometry such that when the base unit 20 is free-standing, it will support the robotic arm 40. In some

embodiments, the base unit **20** may further comprise a moveable cart to provide motion to the system, for example, around a vehicle.

In addition to providing structural support, the base unit **20** may house various other system components such as mechanical controls, electrical controls or both a combination thereof. The base unit may also comprise display screens (now shown) or other mechanisms by which operators may view information regarding operation of the system. Electrical signals or electromagnetic signals can be received from an external input device to control the movements of any component of the system via the control system.

In exemplary embodiments as depicted in at least one of **FIG. 2** to **FIG. 15**, the system comprises a plurality of joint assemblies **50**. **FIG. 2** depicts joint assemblies **50** are positioned between at least one of: adjacent arm segments **41**, an arm segment **41** and base unit **20**, or between an arm segment **41** and connector assembly **30**. Joint assemblies **50** comprise means configured to move between at least a first and a second position and thereby adjusting a position of at least one arm segment **41** relative to the base unit **20** or a position of the connector assembly **30** relative to the base unit **20**.

The robotic arm may comprise a combination of joint assemblies, including but not limited to linear joint assemblies, rotary joint assemblies or other suitable joint assemblies. Other suitable joint assemblies comprise revolute joints, prismatic joints, spherical joints, cylindrical joints, planar joints, continuous joints, universal joints, hinge joints, slider-crank joints, pivot joint, helical joints, ball joints, flexure joints, sliding contact joints, cam-follower joints, and bearing joints. Such joint assemblies, when employed in combination, enable the robotic arm, and preferably, the connector assembly to achieve multiple degrees of freedom to facilitate the mating of a charging connector with the EV charging port. In the present disclosure, the terms charging port, socket, charging inlet, or simply, inlet, may be used interchangeable.

The features and configuration of a joint assembly may vary depending on the specific design and operational requirements of the system. Linear joint assemblies facilitate a translational motion, allowing an arm segment to translate with respect to another arm segment, connector assembly, base unit, or a combination thereof. Rotary joint assemblies enable a rotational movement, facilitating the pivoting or turning of one or more robotic arm segments another arm segment, connector assembly, base unit, or a combination thereof.

As depicted in FIG. 2, an exemplary system 10 comprises a connector assembly 30 configured to support an electric vehicle connector 31. The connector assembly 30 is configured to either in a fixed or releasable manner, support an electric vehicle connector 31. The connector assembly may comprise a release mechanism, which enables the controlled disengagement of the EV connector from such connector assembly. Such controlled disengagement may enable a swift release in the event of an operator triggered event, such as emergency situation.

The connector assembly 30 can be realized as any suitable means to support the electric vehicle connector, such as a flange, either fixed or moveable, a receptacle, or an interface structure. In certain embodiments, the connector assembly comprises a flange assembly, which may be either fixed or moveable. The flange can be designed with a set of locking mechanisms or clamps to securely hold the electric vehicle connector in place during the charging process. This flange assembly may be vertically or horizontally oriented, depending on the specific requirements of the charging station. The connector assembly may be configured as a receptacle interface comprising alignment guides, locking pins, or magnetic locks to ensure a reliable support and connection between the connector assembly and the connector. In some cases, the connector assembly may utilize an interface structure which incorporates geometric shapes, surfaces, or channels that interact with corresponding features on the electric vehicle connector. By this implementation, the connector assembly supports the connector, preventing disengagement during charging. The connector assembly may comprise a rapid release mechanism to enable rapid and controlled disengagement of the electric vehicle connector 31 from the connector assembly or from at least a section thereof. It can be actuated manually or automatically, providing flexibility in disconnecting the connector in emergency situations or when the charging process is completed.

In further reference to FIG. 2, the system comprises a compliance assembly 100 positioned between the robotic arm and the connector assembly 30. This compliance assembly 100 enhances the system's capability to compensate for unexpected movements during the charging process, thereby ensuring reliable and efficient electric vehicle charging. In this example, such compliance assembly 100 acts as an intermediary component between the robotic arm 40 and the connector assembly 30 and is designed to provide a controlled degree of flexibility and adaptability to the connector assembly's movements, allowing it to respond to unforeseen variations in the positioning and orientation of the electric vehicle's charging port.

The compliance assembly may comprise a compliant element selected from at least one of: compliant spherical mechanisms, mechanical springs, pneumatic elements, pneumatic actuators, rubber/silicone elements, flexures, and combinations thereof.

Compliance assemblies may be distributed throughout the system, between the base unit and the connector assembly. Preferably, the compliance device is configured to enable a compliance in different degrees of freedom, such in at least one of: i) a translation along at least one of the X, Y and Z axes and ii) a rotation around at least one of the X, Y and Z axes. By such implementation, the connector assembly is able to adjust its orientation to match the charging port's angle. The compliance assembly may incorporate a Stewart platform configuration comprising a plurality of pre-tensed springs, such as linear springs. Such springs can be mechanically coupled to the connector assembly on one end and mechanically coupled to the robotic arm on the other end, whereby the connector assembly is provided with a controlled compliance in multiple directions. Each spring is attached to both the robotic arm and the connector assembly, forming an hexapod-like structure. The Stewart platform configuration with linear springs can provide compliance in at least three degrees of freedom and up to six degrees of freedom, allowing to compensate for unexpected movements in any direction, whether it's lateral shifts, tilting, or rotation of the connector assembly. Such springs can be individually tensioned at varying levels to modify compliance characteristics, aligning with specific use cases. For example, in scenarios where precise compliance in either translation or rotation is required, the tension in the corresponding springs can be selectively adjusted. In some embodiments, the compliance assembly comprises force sensors selected from at least one of piezoelectric sensors, strain gauges, or load cells, which are configured to provide feedback on compression and tension forces.

With further reference to FIG. 2, the system further comprises a control system 60, a connector assembly 30, and a compliance assembly 100. The control system 60 is designed to autonomously manage and oversee the various operations and functionalities involved in the charging of an electric vehicle (EV). The control system comprises a combination of hardware components, software algorithms, and other components that collectively enable it to monitor, analyse, and make decisions based on data received from various sources, including sensors, operational parameters, and external inputs. The control can communicate with external systems or operators as needed, exchange data, and provide status updates, thereby facilitating remote monitoring and management of the charging process.

With reference to **FIG. 3**, a system is depicted, comprising a base unit **20** positioned in a substantially horizontal manner, a plurality of arm segments **41** serially linked through joint assemblies **50**. The system further comprises a control system **60** (not shown), a connector assembly **30**, and a compliance assembly **100**. The base unit **20** further
5 comprises a connector housing **70** defining a geometrical volume for at least partially housing the connector assembly **30**, preferably a connector charging interface **31**.

Referring to **FIG. 4**, a system is depicted, comprising a substantially elongated base unit **20** positioned in a vertical direction and a series of arm segments **41**, **42** and **43**. The system comprises joint assemblies **50**, **51** and **52**. In this embodiment, arm segments **42**
10 and **43** are preferably coupled through a linear joint assembly **51** which enable such segments to undergo a linear displacement as well as through a rotary joint assembly **52** which enables a pivoting motion. Joint assembly **51** and rotary joint assembly **52** are positioned between the base and arm segment **42**, allowing for a substantially linear
15 displacement of the arm segment **42** along the Z-axis, which can be achieved through various means, including manual or actuated displacement. Rotary joint assembly **52** enables a pivot of the arm segment **42** about the Y axis. Rotary joint assembly **52** further enables a pivot of the base unit about the Z axis. In each case, such rotation may be achieved through manual or actuated rotation.

FIG. 5a and **FIG. 5b** show an embodiment of the system wherein the robotic arm **40** is in a stowed position **5a** and in a deployed position **5b**, respectively. Rotary joint assemblies
20 **52** allow a pivot of the base unit around the Z axis.

Referring to **FIG. 6**, a system comprises a plurality of arm segments **41**, **42**, **43**, **44**, **45**, a rotary **52** and a linear joint **51** assembly between two arm segments **42**, **43** and arm segments **44** and **45**, a linear joint assembly **51** which allows for a vertical displacement
25 base unit **20** and arm segments **42**, **44**. Rotary joints **52** between base unit **20** and arm segments **42** and **44** allow for a further pivoting motion of such arms segments.

FIG. 7 depicts a connector changing system **90**, including a connector coupler **91**, a connector changer **92**, and a connector mounter **93**. The connector mounter **93** can be supported by various means, including any type of support **94**, or it may also be attached
30 to an external support such as a wall, ceiling, or other suitable structure (not shown).

The robotic arm and/or connector assembly is designed to manipulate multiple electric vehicle connectors, facilitating engagement, disengagement, and positioning of different EV connectors, as depicted for example, in **FIG. 7**. To enable the transition between

different EV connectors, the system incorporates a tool change system, referred to as a connector changing system **90** in this disclosure. The connector changing system **90**, in one embodiment, comprises three main components: a connector coupler **91**, a connector changer **92**, and a connector mounter **93**.

5 The connector coupler **91** comprises means to couple to a charging connector **31** and can be used with various types of charging connectors **31**. The connector coupler **91** is designed to be selectively and securely fastened to the connector changer **92**, which in turn can be coupled to the connector assembly **30**. Additionally, the connector coupler **91** may be mounted onto or detached from the mounter **93**. The connector changer **92** is
10 usually mounted at the distal end of the robotic arm **40**.

The connector changer **92** is designed to manipulate the connector coupler **91**, which comprises tasks such as mounting or unmounting the coupler **91** onto or from the mounter **93**, as required.

The mounter **93**, on the other hand, is responsible for securing the coupler **91** and can
15 preferably accommodate multiple connector couplers **91**, each of which can be manipulated by the changer based on the specific charger requirements. In some embodiments (not shown), the mounter **93** may also be affixed to a structure, such as a wall, cradle, or shelf. By this implementation, the system is able to switching between various EV connectors, enhancing the system's versatility in serving multiple EVs
20 simultaneously.

As depicted in **FIG. 8a**, base unit **20** may comprise at least one charging cable attachment means **110**, **111**, configured to position an end of the charging cable **80** at a position to effectively counteract a non-desirable influence of the cable **80** on the motion of the robotic arm **40**, the motion of the connector assembly **30**, or on any step of mating process, such
25 as preventing cable weight from hindering the robotic arm's operations.

Attachment means **110**, **111** are configurable to position an end of the charging cable at variable heights and at variable distances from the robotic arm **40** or a portion thereof, accommodating different vehicle charging cable and connectors. The attachment means may comprise a pivotal rotational joint where it connects to the base unit **20**. Such pivotal
30 rotational joint facilitates rotational movement, allowing the attachment means **110**, **111** to adapt to various charging scenarios and to further reduce the influence of the weight or stiffness of the cable on the motion of the robotic arm or the connector assembly. It ensures

that the charging connector **31** can be aligned with the electric vehicle's charging port, regardless of the port's location or orientation.

As depicted for example in **FIG. 8a**, the charging cable **80a** may be fully integrated into the robotic arm **40**. This integration reduces external cable exposure, effectively isolating the cable from potential contact with operators and lowering associated safety risks. By this implementation, the system is further able to obviate the need for liquid cooling systems that are traditionally required to dissipate the heat generated during high-power charging and instead allows for the robotic arm itself to act as a protective barrier, preventing any external direct contact with the high-temperature cable.

As depicted for example in **FIG. 8b** a supporting arm **113** is provided, to support a charging cable **80** and to provide a further range of motion to such cable. The supporting arm **113** is mechanically coupled to the base unit **20** and is configured to pivot through a pivot range to dispose the charging cable **80** such that the connector **31** can be manipulated by the robotic arm while minimizing the influence of the weight of the charging cable **32**. Preferably, the supporting arm **113** is coupled to the base unit **20** through a rotational joint **112**. The supporting arm **113** permits maintaining the charge cable **80** in an elevated, above ground position, protects cable from ground, contamination, chafing/abrasion, dirt, snow and ice etc. protects against trip hazards to passersby, and also avoids vehicles running over the cable **80**, as well as preserving end connectors/fittings from damage and contamination.

The supporting arm may be mechanically coupled to fixed structure such as a wall, floor, or ceiling (not shown) and coupled using likewise coupling means such as a rotational joint. The supporting arm may comprise one or more joints, such as rotary or linear joints. In some embodiments, the supporting arm may be an articulated arm, a telescopic arm, a rotational arm, among others. The supporting arm **113** may further comprise a cable attachment means **114**, such as depicted in **FIG. 8b** which may be configured to rotate or to translate along or about such supporting arm **113**. The supporting arm **113** may also comprise biasing means (not shown), such as a spring loaded mechanism to retrieve the supporting arm **113** to a desired position, such as a retracted or extended position. The biasing means is positioned in such a way that it exerts a force to retract the supporting arm **113** back to its retracted position when it is not actively holding or manipulating the charging cable **80**. When the supporting arm **113** is extended or pivoted to position the charging cable **80** for use by the robotic arm, the biasing means stores potential energy in the coiled spring. Once the robotic arm completes its task and retrieves the connector, the stored energy in the spring causes the supporting arm to retract back to the retrieved

position, effectively "winding up" the spring. This retraction minimizes the risk of the charging cable being left hanging or causing obstructions when not in active use.

As depicted by FIG. 9a, an exemplary system comprises two arm segments 42 and 43 and a rotary joint assembly 52 between such arm segments, and a rotary joint 52 assembly between the base unit 20 and the most proximal arm segment 42, forming as such a SCARA type of arm. As depicted by FIG. 9a, an exemplary system comprises, at a distal end of the robotic arm two arm segments 44 and 45 and a linear joint assembly 51 between such arm segments which allows for a linear displacement of a most distal arm segment 45. Such assembly including two arm segments 44, 45 and a linear joint assembly 51 may be referred to as a mating section of the robotic arm.

A mating section can be coupled to an adjacent arm segment and/or connector assembly through linear and/or rotary joint assemblies, which can impart several degrees of freedom to said connector assembly. Depending on the specific use case, such joint assemblies may be either fixed (static), actuated, or manually adjustable, and they may confer additional pitch, roll, and yaw capabilities to the connector assembly. In certain configurations, the mating section may be positioned at a pitch angle greater than zero, facilitating the connector assembly in achieving a larger vertical displacement along the z-axis. This implementation combines the vertical displacement along the z-axis with the displacement along the x-axis, resulting from the SCARA movement. By this implementation, the system may compensate for any constraints in vertical displacement along the z-axis originating from either the base unit or the robotic arm.

Referring to FIG. 9a and FIG 9b an exemplary system is depicted, comprising a base unit 20, a plurality of arm segments 42, 43, 44, 45, 46 linked through joint assemblies 50, 51, 54 forming a SCARA-type robotic arm. The system according to this embodiment further comprises a connector housing 70. The system further comprises a connector assembly 30, and a compliance assembly 100. Figure 9b illustrates the degrees of freedom which the connector assembly 30 can achieve given this configuration. With reference to FIG. 9a, the system comprises rotary joints 52 and a linear joint 51 between the connector assembly 30 and the arm segment 44. In such embodiment, the combination of different joint assemblies may allow the connector assembly 30 to be moved in at least six degrees of freedom as depicted in FIG 9b.

Referring to FIG. 10a a system is depicted, comprising a base unit 20, a plurality of arm segments 42, 43, 44, 45, 46, 47 linked through joint assemblies 50, 51, 52. A linear joint assembly 51 between base 20 and arm segment 42 allows for a vertical displacement of

the robotic arm **40** and as such, an additional degree of freedom to the motion of the connector assembly **30** as depicted in **FIG. 10b**.

Referring to **FIG. 11** a system is depicted, comprising a base unit **20** which is supported on a base **21**. Linear displacement means **51** allow for a linear displacement of the base unit **20**.

As depicted by **FIG. 11** an exemplary robotic arm comprises a shoulder joint assembly **50a**, an elbow joint assembly **50b**, a wrist joint assembly **50c**. Distally to the wrist joint assembly **50c**, the connector assembly **30** is mechanically coupled.

Joint assemblies may be designed to be fixed or static, serving as structural connectors between two arm segments, between the base and an arm segments, or between the robotic arm and the connector assembly, without enabling movement or articulation therebetween. Such static joint assemblies may be any of a linear or rotary joint which is fixed or static by configuration or any joint assembly which is static or fixed by design.

Joint assemblies may be actuated, either via active or passive means. As used herein, active actuation involves the deliberate application of external forces or energy to initiate and control the motion of the joint assembly. Actuation members comprise any suitable means such as electromagnetic actuation means, motorized actuation means (electric motors, stepper motors, or other motorized components to actively drive and control the joint assemblies), piezoelectric actuation means, solenoid actuation means (implementation of solenoids to exert magnetic forces for actuation purposes), hydraulic actuation means, pneumatic actuation means, among others.

Passive actuation refers to the inherent response of the joint assembly to environmental or intrinsic factors, such as mechanical forces or temperature gradients, resulting in motion without the explicit application of external forces.

Actuator members may be any suitable actuating means for driving said joint component and are preferably electric drive devices, such as stepper motors, servo motors, hydraulic motors, pneumatic motors and combinations thereof.

Referring to **FIG. 12**, the robotic arm **40** is in a stowed position and whereby the connector assembly **30** is at least partially engaged by the connector housing **70**.

FIG. 13a and **FIG. 13b** depict embodiments of the connector housing, including an external enclosure **70a**, an inner enclosure **70b**, and a compartment for power contacts **70c**. **FIG.**

13b depicts a section of a connector assembly **30** in accordance with embodiments of the invention. Connector assembly supports a charging connector **34**.

As depicted in **FIG. 13a** and **FIG. 13b**, the connector housing **70** may comprise at least one of: an external enclosure **70a**, an inner enclosure **70b**, and a compartment for power contacts **70c** as depicted in **FIG. 13a**. The function of the inner enclosure comprise ensuring electrical insulation, mechanical strength, and/or prevent water and dirt contamination. The inner enclosure **70b** may comprise a protective material, such as a soft epoxy and/or silicone-based material. By such implementation, the connector housing can protect the connector assembly when the system is not in operation. Preferably, the inner enclosure **70b** allows connector assembly **30** and/or the connector **31** to effectively remain sealed against the ingress of water and dust (preferably at an IP rating of 24, 44 or other suitable rating) while the robotic arm **40** is in the stowed position.

The connector housing **70** may be affixed to a plate or any similar component coupled to the base unit **20**, which may be opened or closed, via a hinge door assembly or a door fold assembly, depending on the specific design requirements. In this configuration, the connector housing's plate is attached to the base unit or arm segment and is designed to pivot or fold about a predetermined axis. When the robotic arm **40** is in a stowed position or not in use, such plate can be closed, sealing the connector assembly **30** within the housing **70**. In some variations of this embodiment, the connector assembly **30** can be utilized to engage the opening or closing of the connector housing's plate. As the robotic arm moves forward or backward, this motion can trigger the plate to open or close automatically.

With reference to **FIG. 14a**, base unit **20** and two arm segments **41** and joint assemblies **50** are depicted. **FIG. 14b** depicts joint member **55**, an actuator member **54**, a transmission member **56**, and a brake component **57**. Motor section which is positioned on an arm segment and a joint section coupled to the motor section via a transmission assembly.

With reference to **FIG 14b**, an expanded view of an exemplary arm segment **41** and joint assembly **50** is depicted. **FIG 14b** depicts joint members **55**, actuator members **54**, transmission members **56**, and brake members **57**. Joint members **55** in this example are rotary joints, enabling rotary movement between two adjacent arm segments **41** or between a base unit **20** and an adjacent arm segment as depicted in **FIG. 14a**. Joint members **55** provide a pivotal connection. Actuator members **54** in this example are mounted on each arm segment, and so are configured to deliver rotational force to drive the joint's movement and preferably, to provide control over the rotary motion of the robotic

arm. Actuator members are controlled by the control system. Transmission members 56 allow transferring torque generated by the actuators 54 to the joint members 55. Transmission members 56 may incorporate various components such as gears, pulleys, belts, or other mechanical elements, depending on the specific design requirements.

5 Brake members 57 are designed to immobilize or restrict the movement of the joint member 55 and as such, restricting the movement of the corresponding arm segment arm with respect to any adjacent arm segment or base unit. A brake member 57 can be any type of brake, such as an electromagnetic brake, a spring loaded brake or any other type of suitable brake mechanism.

10 Brake members 57 may be any suitable brake component that allows preventing a movement of a joint assembly, an arm segment, a connector assembly or any combination thereof, relative to another moving or non-moving component of the system, such as the base. A brake member may be at least one of a joint brake type and a motor brake type, or a combination thereof. A brake member may be selected from any one of an
15 electromagnetic brake, a friction brake, an hydraulic brake, a spring loaded brake, and combinations thereof. As used herein a joint assembly is locked when the movement of such joint assembly is either partially or fully restricted.

The robotic arm is configured to transition from a locked state to an unlocked state, and vice versa. Locking prevents movement of components, such as of adjacent arm segments
20 relative to each other, or movement from an arm segment relative to the base unit, movement from the connector assembly relative to an arm segment or to the base unit, wherein the locking is carried out by the locking of one or more joint assemblies coupling such components.

One or more joint assemblies may be locked and unlocked selectively and independently
25 of other joint assemblies. Alternatively, all joint assemblies of the system can be simultaneously locked or unlocked.

Joint assemblies preferably comprise a locking mechanism in which a joint member that couples adjacent arm segments of the robotic arm is locked, preferably, via a brake member, such as an electromechanical brake. In some embodiments, the robotic arm
30 comprises multiple joint assemblies such as rotary joint assemblies and linear joint assemblies. In some embodiments, at least two of the multiple joint assemblies are locked simultaneously. Optionally, all joint assemblies are locked simultaneously. In some embodiments, locking of a joint assembly is performed locally at such joint, for example by mechanical and/or electromechanical components physically located at the joint.

In certain embodiments, brake members are configured as electromagnetic brakes, which utilize electromagnetic principles to control motion. Electromagnetic brakes generally comprise a stationary housing and an electromagnetic coil. The stationary housing is affixed to the arm structure and is positioned in close proximity to the moving part, such as a joint member, that requires control. When electrical current is applied to the coil, it generates a magnetic field. This magnetic field interacts with the joint member, creating either attraction or repulsion forces and limiting the movement of the joint. When the electromagnetic brake is activated, electrical current is provided to the electromagnetic coil, energizing it, and the coil generates a magnetic field, and this field interacts with the moving part and permits that the arm segment or joint remains in a fixed position. When the electromagnetic brake is deactivated, the electrical current to the electromagnetic coil is cut off, ceasing its magnetic field generation; without the electromagnetic force, the brake releases its grip on the moving part and permits the arm segment or joint to move freely as directed by the control system. Thereby, the robotic arm is able to transition between a locked and unlocked state, and vice versa, throughout the complete cycle.

As depicted by FIG. 3, FIG. 9a and FIG. 12a, at least one of the base unit 20 and arm segments 41 comprises a connector housing 70, which defines a geometrical volume for at least partially housing the connector assembly 30, preferably the connector charging interface 31. The connector housing 70 may comprise a box-like structure but can be of any geometry which allows housing or at least partially housing or supporting the connector charging interface preferably when the robotic arm is in a stowed position, as shown in FIG. 12. The connector housing 70 may comprise one or more openings and a plate or any suitable structure on which the connector assembly can rest and to which it can be attached. The connector housing 70 may be fixed (i.e. attached) to the base unit or may be displaceable to accommodate different types, sizes and positions of connector assemblies.

In reference to in FIG. 5a and FIG. 12, a "stowed position" refers to the state of the robotic arm when it is not actively engaged in a charging cycle or any operational task. It is the configuration where the robotic arm is in a retracted or retrieved position, typically positioned in a secure and compact manner. In the stowed position, the robotic arm is stowed away when it is not in use, generally awaiting deployment for charging, maintenance, or other tasks. In this position, the arm is preferably held securely to prevent unintended movement. Thereby, the robotic arm can remain securely held in place, preventing any unintended motion that could potentially lead to damage or misalignment,

optimizes the utilization of available space, ensuring that the arm does not protrude unnecessarily when not in use. Preferably, during the stowed position, and in reference, for example, to FIG. 12, the connector housing 70 is configured to at least partially housing the connector assembly 30, preferably a connector charging interface.

5 In the stowed position, the robotic arm may be held in such position by any mechanism suitable for maintaining the arm in this configuration, such as a pin, either actuated or passive, a latch, or magnetic clasp. Thereby the arm may be transitioned into an unlocked position while remaining stationary, thereby preventing any inadvertent movement.

10 In reference to FIG. 12, in the stowed position, it is preferable for arm segments to be in a substantially parallel position with respect to each other, to allow for a particularly compact configuration. Such disposition can be achieved by having the actuator members 54, joint members 55 and brake members 57 mounted to optimize the distribution of weight and used space within the robotic arm, such as depicted in FIG. 14a and FIG. 14b. Such configuration allows for the construction of arm segments in a compact and short form
15 when stowed, while simultaneously enabling the arm to exhibit a significant reach when extended. This joint assembly members disposition contributes significantly to the system's ability to adapt to confined spaces and reach distant target locations while maintaining structural integrity

20 In the context of the described embodiment, a "deployed position" denotes the state of the robotic arm when it is actively involved in a charging cycle or any other operational activity as depicted, for example, in any of FIG. 2, FIG. 3, FIG. 4, FIG. 5b and FIG. 9a, among others. A deployed position encompasses situations where the robotic arm is initiated for a charging cycle, moving towards the electric vehicle's charging port, or engaged in specific tasks such as connecting or disconnecting the charging connector. In the deployed
25 position, the robotic arm is primarily actively carrying out its intended functions, which may involve articulation, rotation, translation, or other movements necessary for its operation. The term "deployed position" does not refer to a singular fixed static position, but instead encompasses a spectrum of possible positions and orientations that the robotic arm can assume during various operational scenarios. Preferably, deployed position comprises a
30 plurality of deployed positions. These variations of the deployed position are characterized by different degrees of extension, rotation, and articulation, depending on the specific task and requirements at hand.

The system preferably comprises, or is in communication with, at least one sensor means configured to generate sensor data. Sensors comprise, but are not limited to camera

sensors, force sensors, optical sensors, proximity sensors, lidar sensors, ultrasonic sensors, infrared sensors, magnetic sensors, among others.

Sensor data may be a parameter associated to a component of the system or to the environment where the system operates. Sensor data may comprise at least one of: a
5 pose a vehicle, a pose of a vehicle charging port, a distance between the connector and the charging port, a physical or electric connection between the electric vehicle connector and the charging port, an external force applied to robotic arm, and a physical deflection of a component of the system, among others. Sensor data may include a pose of a vehicle or vehicle inlet with respect to any part of the system. Sensor data may include
10 temperature data, indicating the thermal conditions of the charging components; voltage and current data, reflecting the electric characteristics of the charging process; battery state of charge (SoC) information; environmental data, such as ambient temperature, humidity, or air quality; safety interlock status, indicating whether safety mechanisms are engaged; component wear and tear data; time and timestamp data; communication signal
15 strength; error codes or fault data; alignment or calibration data, and combinations thereof.

A camera sensor may be coupled to either the base unit, robotic arm, or connector assembly, enabling it to acquire pose information within the autonomous electric vehicle charging system and its surroundings. Such camera sensor is positioned to capture pose
20 data, including the positioning of system components and the immediate surroundings of the charging station. Preferably, the camera sensor is oriented to collect pose information regarding the electric vehicle and the vehicle's charging port.

As used herein, the pose of an object describes how an object is placed in the three-dimensional space it uses. An object's pose may be determined with respect to a perspective, such as a camera perspective or camera coordinate system. The pose of an
25 electric vehicle charging port may be understood as a position and an orientation of the vehicle's charging port and is in some embodiments represented by a 3D Cartesian position and a yaw of the socket (x, y, θ). In some embodiments, the pose is a 6D pose where the position is defined by a 3D Euclidean distance and the orientation is defined by a roll, pitch, and yaw of the socket. Determination of the electric vehicle inlet pose is useful
30 for describing the pose and orientation of the charging port relative to a camera position of the ACD in order to direct the EV connector, supported by the connector assembly towards a charging port and completing the mating process.

The pose of the vehicle charging port may be obtained from a single image, multiple images from assumably the same pose, multiple images from assumably different poses,

or making use of earlier determined poses. Alternatively, or additionally, the pose of an object may be obtained from a multi-view image or a video. In several embodiments of the present disclosure, pose determination of the socket may be done by a neural network on which a computer vision unit is based on.

5 Preferably, a neural network may be trained to determine the pose through an analysis of one or more images. The estimated socket pose may comprise estimates about the socket dominant axes, roll, elevation, angular position, attitude, and azimuth angle, among others. Alternatively, a neural network may be trained to detect the geometrical features of a socket, which may function as a fiducial marker, based on which a pose estimation
10 algorithm may determine the pose of the socket with respect to the camera.

A neural network, in addition to determining the pose of the electric vehicle charging port, may provide information about a distance between the connector assembly and the charging port, or the charger connector and the charging port. Preferably, the neural
15 network is trained to analyse one or more images captured by cameras positioned within the system, as outlined in previous embodiments. By examining these images and utilizing its learned algorithms, the neural network can estimate the spatial separation between the connector assembly and the charging port in real-time.

A proximity sensor may be attached, coupled and/or mounted on, or to, the base unit, robotic arm, or connector assembly. Proximity sensors can be positioned to provide
20 proximity data, encompassing not only the spatial relationships of system components but also the immediate vicinity surrounding the charging system. Preferably, proximity sensors can be configured to monitoring the presence of objects, individuals, or potential disturbances in the system's proximity and generate such proximity sensor data. This data not only aids in the mating cycle but also enhances situational awareness, allowing it to
25 respond effectively to dynamic conditions.

A force sensor may be attached, coupled and/or mounted on, or to, the base unit, robotic arm, or connector assembly. Such forces may include those stemming from contact with objects or surfaces, resistance encountered during movement, or unexpected external perturbations. The output generated by the external force sensor is preferably used as an
30 input for the control system, which enables the autonomous charging system to react promptly to deviations from the intended trajectory, prevent collisions, and ensure completion of the charging process. Force information may be acquired through the implementation of force/torque sensors in connection with any component of the system, such as the robotic arm, the connector assembly or the vehicle connector. Preferably, the

control system may utilize this sensor's data in conjunction with other sensory inputs to adapt the robotic arm's movements and to initiate corrective actions, where needed.

The computer vision system, using a neural network and camera sensor feedback, may obtain information associated to a physical deflection in any system component, including the robotic arm, connector assembly, compliance assembly and any subcomponent thereof. Such deflection can serve as an indicator of external forces acting on any of such components. In some embodiments, upon detecting significant physical deflection exceeding a predetermined threshold, the control system is configured to initiate a corrective action to address the external force or disturbance.

The system may further comprise means, such as communication means to receive operational data. Such operational data may also include instructions based on system algorithms. Operational data may be associated to at least one of a signal from the vehicle, an instruction from an operator, or a signal from a remote system. In particular, i) signals from the electric vehicle may include information about the vehicle's battery state, charging port location, charging status, and any specific requirements or preferences regarding the charging process, ii) instructions provided by an operator or user of the system may include specifying charging parameters, overriding automated processes, or requesting special actions related to the charging cycle; iii) the system may interact with remote systems, such as a central charging station management system or a grid management system. Operational data received from these remote systems may include grid demand information, tariff rates, and scheduling priorities, enabling the autonomous charging system to make informed decisions.

The system may include a charging port cover handling device, preferably using any suitable means, such as a gripper mechanism, which can be selected from a range of gripper types, including but not limited to a parallel jaw gripper, a vacuum gripper, a finger gripper, a magnetic gripper, or a combination thereof. Depending on the gripper type and the configuration of the charging port and the EV, the device may use mechanical jaws, suction, or flexible fingers to grasp and manipulate the charging port cover. Preferably, the charging port cover handling device is configured to apply a controlled force to open or close the cover, exposing the charging port. A gripper's suction cup may be positioned over the charging port cover, whereby the gripper creates a vacuum seal, effectively holding the cover and permitting the manipulation, i.e., opening and closing of such cover.

The charging port cover handling device may be in communication with the control system which is configured to receive operational and/or sensor data. Upon receipt of a

communication from an EV indicating the readiness for cover handling, the control system initiates a sequence for cover opening or closing. When camera sensors detect data regarding the charging port's pose, the control system may compute an optimal motion path for guiding the gripper mechanism during the operation in order to complete the initiate the cover opening or closing.

The control system is adapted to respond to the occurrence of unexpected or unwanted events during the cover handling process. Such events encompass a spectrum of irregularities, including but not limited to instances where the charging port cover is found to be locked, improperly unlocked, or obstructed in any manner. The control system is configured to acquire updated input from at least one sensor to recognize deviations from the cover handling process. Preferably, data acquired from camera sensors is relayed to the control system, which then leverages this information to determine if the charging port cover is locked, improperly unlocked, or obstructed in any way. The control system may initiate corrective actions associated to the specific nature of the event. For example, if the charging port cover is detected as locked, the control system may initiate a communication with the EV for proper cover unlocking. Similarly, if the cover is found to be obstructed or improperly unlocked, the control system may activate appropriate mechanisms to rectify the situation and facilitate the opening or closing of the cover, such as generating a signal to an operator for further correction. Likewise, the control system may acquire and re-acquire information from at least one of the EV, camera sensors or position sensors and to reconfigure the instructions for the handling of the cover in cases where a position of the charging port cover has shifted throughout the handling process.

In accordance with the first embodiment of the invention, the method for controlling a system for the autonomous charging of an electric vehicle, comprises allowing the robotic arm to transition from an unlocked state to a locked state before mating the connector with the charging port based on received operational and/or sensor data, wherein in the locked state, at least one arm segment is prevented from undergoing a movement with respect to an adjacent arm segment or with respect to the base unit, and wherein in the unlocked state such movement is allowed

The robotic arm is configured to transition between an unlocked state and a locked state before mating the connector with the charging port based on the received operational and/or sensor data. The term "before mating the connector with the charging port" encompasses any moment preceding the actual mating, and it need not be immediately preceding it. Various intermediary steps may take place in between, such as potential repositioning actions to acquire new data. The term "based on the received operational

and/or sensor data" denotes assessing, by the control system, whether the obtained data aligns with the predetermined criteria and thresholds that should allow a mating operation. When the received data satisfies predefined parameters, signifying that the conditions are suitable for a reliable mating process, the control system can allow, or instruct the robotic arm to transition into the locked state. Conversely, if the received data indicates any deviation or conditions that do not meet a predetermined criteria for mating, the control system can maintain the robotic arm in the "unlocked" state. In this state, the system remains adaptable to make necessary adjustments in response to changes or variations detected in the environment.

The control system is configured for monitoring and/or analysing such operational and/or sensor data. In this context, "monitoring" entails the observation and collection of data from various sources, including sensors and operational parameters, throughout the autonomous charging process. Analysing refers to the examination and interpretation of this collected data, which includes activities such as comparing the data with predetermined thresholds and parameters.

The autonomous charging system generally undergoes a charging cycle involving several steps. The charging cycle comprises, but is not limited to the following steps:

guiding the connector assembly towards the vehicle charging port; and

mating the charging connector with the vehicle charging port.

Guiding the connector assembly towards the vehicle charging port involves the controlled actuation of the robotic arm supporting such connector assembly. The guiding typically entails using sensor and/or operational data, algorithms, and control commands to ensure the connector assembly approaches the vehicle charging port accurately.

Mating the charging connector with the vehicle charging port entails making the physical connection between the charging connector and the charging inlet on the electric vehicle.

The charging cycle may include at least one of the following: repositioning the robotic arm as necessary to optimize alignment; acquiring sensor or operational data for precise positioning; initiating the charging process; monitoring and adjusting the charging parameters; completing the charging process; unmating the charging connector from the vehicle charging port. The charging cycle may include intermittent pausing or interruption of the cycle for safety and system optimization; and establishing communication with the EV or an external remote system for data exchange and coordination. The charging cycle

may encompass any other necessary steps to enable the autonomous charging system to reliably and autonomously charge an electric vehicle (EV).

Throughout any step of the charging cycle, the control system can transition the robotic arm from an unlocked state to a locked state, and vice versa, as many times as needed
5 depending on the case, and the particular stage of the charging cycle.

The sequence of these steps can be adjusted or some steps may be reiterated depending on the specific circumstances. Throughout any step of the charging cycle, the control system is configured to monitoring and analysing such operational and/or sensor data.

The method includes initiating a corrective action if the analysis of the operational and/or
10 sensor data indicates that corrective action is needed to allow the system to complete the mating of the connector with the charging port. Such corrective action becomes necessary in multiple instances when the operational and/or sensor data exhibits deviations beyond, or falls outside of, predetermined thresholds or ranges, or when specific predetermined conditions are either met or not met, wherein such predetermined thresholds or ranges
15 are those predetermined to enable system to complete the mating of the connector with the charging port.

The term "initiating" encompasses a broad spectrum of actions, including instructing, continuing, halting, interrupting, or undertaking any relevant action as necessitated by the analysis of operational and/or sensor data. The term "to complete the mating" extends
20 beyond the mere physical joining of the charging connector and the charging port. It encompasses any and all requisite procedures, inclusive of but not limited to steps facilitating an appropriate connection, charging, and disconnection, that enable the autonomous charging system to proficiently charge an electric vehicle (EV).

Other corrective actions may include: restarting a new charging cycle; adjusting a mating
25 angle or an orientation of the charging connector; initiating a diagnostic self-check to identify any system anomalies; activating an emergency stop to halt the mating process in case of critical issues or when triggered by an operator or remote system; notifying an external control system or operator for manual intervention, among others.

At any stage of the charging/mating cycle, the control system may output a control
30 command to transition the robotic arm from a locked state to an unlocked state and vice versa, in response to receiving information from the one or more sensors detecting sensor information out of a predetermined threshold.

Allowing the transition of the robotic arm from an unlocked state to a locked state, and vice versa, may enable the system to make necessary adjustments while determining the pose of the charging port or the charging port cover. This can be advantageous when the camera sensor is mechanically coupled to the robotic arm and where a pose of the charging port or charging port cover needs to be determined from a different position. This is further advantageous when the camera sensor is not mechanically coupled to the robotic arm but a moving part of the robotic arm obstructs the camera view for pose determination which would require a repositioning of such moving part. Likewise, if sensor data indicates a change in the position of the charging port after an initial alignment or after an initial pose determination, if the pose of charging port falls out of a level of confidence, or if pose of the charging port or charging port cover cannot be determined using the current input from the camera sensor, the control system may transition the robotic arm to an unlocked state, allowing the system to gather new pose estimation data, guide and/or align the connector assembly based on such new data, and transition the arm to the locked state to initiate or continue such mating. The control system may allow the robotic arm to transition from the unlocked state to the locked state when such pose data is within a predetermined threshold for mating, such pose data being at least one of the charging port pose and the connector assembly pose. Likewise, the control system may allow the robotic arm to transition from the unlocked state to the locked state when the connector assembly is at a predetermined position range for mating. This range might include a specific distance threshold, such as within 1-10 millimeters, to guarantee close proximity. Angular alignment within a certain degree tolerance (e.g., 5 degrees) might be required to proper insertion

If sensor data indicates a distance between the connector assembly and the vehicle charging port that exceeds a predetermined threshold or falls outside a predefined confidence level during any step of the mating/charging cycle, the control system may initiate specific corrective actions to optimize the mating process. Such actions may include, but are not limited to: transitioning the robotic arm to the unlocked state enabling the robotic arm to adjust its position and orientation; repositioning the robotic arm to bring the connector assembly closer to the vehicle charging port, thereby reducing the detected distance; initiating a data refresh operation to obtain new sensor data, which may include updated distance measurements; reattempting the mating process by guiding the connector assembly towards the vehicle charging port with adjusted parameters for improved alignment.

If sensor data indicates a physical or electrical connection between the electric vehicle connector and the vehicle inlet/charging port during the mating process, the control is

configured to detect this connection and assess such connection. In the event that sensor data indicates issues or irregularities in the connection, the control system initiates specific corrective actions to optimize the mating process, such as those mentioned herein. For instance, once such electrical connection is detected, the control system may allow the robotic arm to transition into the locked state to complete the mating.

The control system is configured to monitor parameters such as any force acting on the robotic arm, the connector assembly, or any other component of the system. If any of such parameters exceed a predetermined range or fall out confidence levels, the control system can configured to transition the robotic arm from a locked state to the unlocked state, or vice versa. For instance, while the robotic arm is in the locked state, the control system monitors the force exerted on the connector assembly, ensuring that it remains within a predetermined range and confidence levels. Should there be a significant deviation in this force parameter, indicating the potential for excessive stress or misalignment, the control system can initiate a transition to the unlocked state in order to facilitate a repositioning of the robotic arm or for acquiring new sensor data. Once the control system acquires data indicating that that a force acting on the connector assembly is within a predetermined range, it can re-initiate the guiding of the connector assembly towards the charging port and subsequently transitioning the arm to the locked state once sensor or operational data indicates that position of the connector assembly is within a predetermined range. In some cases, such predetermined range is dependent on the position of the connector in relation to the charging port.

The control system may allow the transition the robotic arm from a locked state to an unlocked state, and vice versa based on specific input parameters related to socket pose estimation. As the robotic arm remains in the locked state, such as when the mating of the connector takes place, the control system continuously monitors pose estimation data, ensuring that parameters remain within predefined confidence levels and thresholds. In the event of a significant parameter deviation, signifying potential inaccuracies in the pose estimation, the control system can either, acquire new pose data, make a short repositioning of the arm to acquire new data, or transition the arm to an unlocked state in order to allow for a repositioning and/or acquiring of new sensor data from a new position. This transition allows the robotic arm for repositioning while triggering the acquisition of pose estimation data. Once the control system verifies that pose estimation data is within a predefined confidence interval, it can resume the guiding or mating of the connector.

If operational data associated to any step of the charging cycle is received, the control system may evaluate this operational data and respond appropriately to allow the system

to complete the mating of the connector with the charging port. This encompasses scenarios related to operational data from the vehicle, which may include, but are not limited to: receiving data indicating changes in the vehicle's state, such as powering on or off, which may require adjustments to the charging cycle to accommodate the vehicle's power requirements and safety considerations; receiving data related to the vehicle's battery status, charge level, or charging preferences, allowing the control system to adapt the charging cycle to meet the specific needs of the vehicle; receiving data indicating vehicle movement, such as repositioning or shifting, and taking corrective actions to achieve a suitable connection between the connector assembly and the vehicle inlet/charging port; monitoring signals for emergency situations or safety concerns, triggering a transition of the robotic arm to the unlocked state or initiating an emergency shutdown procedure if necessary to ensure the safety of the charging process, or a combination thereof.

At any stage of the charging/mating cycle the control system may receive a socket pose parameter and transition the robotic arm from an unlocked state to locked state when the socket pose parameter is within a predetermined acceptable range for mating. In some cases, the control system is configured to receive a socket pose parameter and transition the robotic arm from a locked state to an unlocked state when the socket pose parameter is not within a predetermined acceptable range for mating.

Predetermined acceptable ranges or thresholds for socket pose parameter can be adjusted on a case by case scenario, and can include for example, X, Y, and Z coordinates ranges, thresholds for pitch, yaw, and roll angles, and distance thresholds, so that if the socket pose parameter indicates that the connector is within the acceptable distance range, the control system can lock the arm for mating.

In the context of the described embodiment, during a locked state, the control system, directly, or indirectly through the activation of system components, is configured to prevent at least one arm segment from undergoing at least one of an articulation, a rotation, a translation, an actuation, a displacement, or combinations thereof with respect any other non-moving system component or with respect to the fixed world. In a locked state, as previously described, the control system is configured to restrict the robotic arm's range of motion and functionalities.

This limitation can occur in both the stowed and deployed positions, but it is primarily advantageous and preferable during a deployed position.

In certain scenarios, such as when the robotic arm is stowed, there may be instances where it is beneficial to apply limited restrictions on arm movement. For instance, when the arm is being retracted into its stowed position, the control system can impose certain restrictions on articulation, rotation, translation, actuation, or displacement to ensure a safe and controlled stowage process and stowed position. By such implementation, the robotic arm can be transitioned to the locked state during the stowed position and as such, this may prevent any further movement of the arm, safeguarding it against unauthorized access, tampering, or vandalism.

Preferably, during the stowed position, and in reference, for example, to FIG. 12, the connector housing is configured for at least partially housing the connector assembly 30, preferably a connector charging interface. By permitting such engagement, undesirable arm movements can be restricted without necessarily having the robotic arm in a locked state.

An advantage of the locked state is realized during the deployed position of the robotic arm's operation. In this context, the control system is configured to more significantly restrict at least one arm segment from undergoing articulation, rotation, translation, actuation, displacement, or their combinations. This restriction is particularly valuable during the mating cycle, where precision and stability are desired. In particular, by transitioning into a locked state and as such restricting the arm's movement during the deployed position, for example, prior to the mating of the charging connector with the charging port, the control system can ensure that the arm remains in a predetermined configuration. Such locked stage can prevent any unintended shifts or adjustments that could lead to misalignment with the electric vehicle's charging port.

Furthermore, locking the arm's segments in place during the deployed position guarantees that it maintains a desired orientation and position for controlled mating and charging. In some cases, once the mating has been completed, the arm segment is transitioned to an unlocked state. Furthermore, the activation of a locked state enables a reduction in the overall force exerted by system components to complete the mating process. In particular, when the robotic arm is in the locked position, mainly the actuators at the distal end of the robotic arm can be actuated for the mating step. As such, during the mating or unmating phase, the control system can selectively activate actuators positioned at the distal end of the robotic arm. Such actuators are responsible for the final alignment and mating of the charging connector with the electric vehicle's charging port. In parallel, the control system can control that the remaining joints and segments of the arm remain locked, preventing

any unintended movement or articulation. Such a selective locking significantly reduces any potential resistance or force required during the mating process.

5 Terms like "configured to" include components in various states unless specified otherwise. Conditional terms ("can", "may", etc.) suggest some embodiments include certain features, while others may not. Words like "comprising" and "or" are inclusive, allowing for additional elements or options. The term "allow" covers actions like permitting and enabling. Method steps do not need to follow a specific order to achieve desired results.

CLAIMS

1. A method for controlling a system for the autonomous charging of an electric vehicle, the system comprising: a connector assembly to support a connector for mating with a vehicle charging port; a base unit; a robotic arm comprising a plurality of arm segments; and control system configured to receive operational and/or sensor data, wherein the method comprises:
- 5
- guiding the connector assembly towards the vehicle charging port by actuation of the robotic arm;
 - allowing the robotic arm to transition from an unlocked state to a locked state before mating the connector with the charging port based on the received operational and/or sensor data, wherein in the locked state, at least one arm segment is prevented from undergoing a movement with respect to an adjacent arm segment or the base unit; and wherein in the unlocked state such movement is allowed;
 - 10
 - effecting the mating of the connector with the charging port by moving the connector assembly while monitoring and analysing such operational or sensor data ; and
 - 15
 - initiating a corrective action if the analysis of the operational and/or sensor data indicates that corrective action is needed to allow the system to complete the mating of the connector with the charging port.
 - 20
2. Method according to claim 1, comprising comparing the operational and/or sensor data with at least one predetermined operational and/or sensor data and using a result of the comparison to determine whether a corrective action is needed.
3. Method according to any one of claims 1 or 2, comprising allowing the robotic arm to transition between the unlocked state and locked state when such operational or sensor data is within a predetermined range.
- 25
4. Method according to any one of the preceding claims, comprising carrying out at least one of the following actions such that the system is able to complete mating of the connector with the charging port: i) transitioning the robotic arm to the unlocked stage;
- 30
- ii) transitioning the robotic arm to the locked stage; iii) repositioning the robotic arm;

or iv) obtaining new, or updated operational or sensor data; or v) reattempting the mating.

5. Method according to any one of the preceding claims, comprising receiving:

- 5 – sensor data associated to at least one of: a pose of the charging port, a pose of the connector assembly, a distance between the connector and the charging port, a physical or electric connection between the electric vehicle connector and the charging port, an external force applied to robotic arm, and a physical deflection of a component of the system; and/or
- 10 – operational data associated to at least one of a signal from the vehicle, an instruction from an operator, or a signal from a remote system.

6. Method according to any one of the preceding claims, comprising receiving pose data of the connector assembly and allowing the robotic arm to transition from the unlocked state to the locked state when such pose data is within a predetermined threshold for mating.

15 7. Method according to any one of the preceding claims, wherein during the locked state, at least two arm segments are prevented from undergoing a movement and at one arm segment is allowed to undergoing a movement, in each case with respect to an adjacent arm segment or the base unit.

20 8. Method according to any one of the preceding claims, comprising allowing the robotic arm to undergo more than one transition between locked and unlocked states prior to the mating.

25 9. Method according to any one of the preceding claims, comprising receiving sensor data associated to an external force acting on the connector and initiating a corrective action when such sensor data deviates from a predetermined range, and wherein such threshold is dependent on the position of the connector in relation to the charging port.

30 10. Method according to any one of the preceding claims, comprising allowing the transition of the robotic arm between a stowed position and a deployed position; wherein during the stowed position, the connector assembly, and preferably the charging connector is at least partially engaged by a connector housing, and during the deployed position the connector or connector assembly is not engaged by the connector housing.

11. Method according to any one of the preceding claims, comprising mating the connector with the charging port during the locked state by allowing the robotic arm to apply a temporarily higher force than a force applied while the robotic arm is in an unlocked state.
- 5 12. Method according to any one of the preceding claims, comprising allowing the transition of the robotic arm from a locked state to an unlocked state at any moment after the mating of the charging connector with the charging port.
13. Method according to any one of the preceding claims, comprising allowing the transition of the robotic arm into a locked state prior to the unmating.
- 10 14. A system for autonomously charging an electric vehicle, comprising:
- a base unit;
 - connector assembly to support a connector for mating with a vehicle charging port;
 - a robotic arm positioned between the base unit and connector assembly and comprising a plurality of arm segments,
 - 15 – a control system configured to receive operational and/or sensor data and to guide the robotic arm and connector assembly towards the vehicle charging port;
- wherein the robotic arm is configured to transition between an unlocked state and a locked state before mating the connector with the charging port based on the received operational and/or sensor data, wherein in the locked state, at least one arm segment is
- 20 prevented from undergoing a movement with respect to an adjacent arm segment or base unit; and wherein in the unlocked state such movement is allowed; and
- wherein the control system is configured for monitoring and analysing such operational and/or sensor data and initiating a corrective action if the analysis of the operational and/or sensor data indicates that corrective action is needed to allow the system to
- 25 complete the mating of the connector with the charging port
15. System according to claim 14, wherein the robotic arm is configured to transition between a stowed position wherein the connector assembly is at least partially engaged by a connector housing, and a deployed position wherein the connector assembly is disengaged from the connector housing.
- 30 16. System according to any one of claims 14 or 15, wherein at least one joint assembly comprises a joint member and a braking member and the control system is configured

to activate and deactivate such braking member to transition the robotic arm between the locked state and unlocked state, and vice versa.

- 5 17. System according to any one of claims 14 to 16, wherein the control system is configured to receiving pose data of the connector assembly and allowing the robotic arm to transition from the unlocked state to the locked state when such pose data is within a predetermined threshold for mating.
18. System according to any one of claims 14 to 17, wherein the control system is configured trigger a short-term partial locking of the joint assemblies to effectively reduce any momentum that the robotic arm may be subject to.
- 10 19. System according to any one of claims 14 to 18, wherein the control system is configured for mating the connector with the charging port if a distance between the connector and the charging port is lower than or equal to a predetermined threshold.