

METHOD AND SYSTEM FOR CALIBRATING AN AUTONOMOUS CHARGING DEVICE (ACD)

INTRODUCTION

The present invention relates to a method for calibrating one or more autonomous charging devices (ACD) and/or components thereof, the ACD comprising an end effector for supporting and moving a vehicle charging connector, a motion control unit, and a computer vision unit for socket-pose estimation, the computer vision comprising at least a baseline neural network, the motion control unit being configured to control the motion of the effector for plugging the connector into a vehicle socket using a pose estimation from the computer vision unit.

10 TECHNICAL FIELD OF THE INVENTION

The present invention generally relates to actuated autonomous charging devices (ACD's) and methods and systems related thereto, which enable the autonomous charging of electric vehicles. Methods and systems in accordance with the invention aim to improve the ACD's performance reliability and continued operation.

15 BACKGROUND OF THE INVENTION

Improving performance and reliability in robotic systems, and in particular in robotic autonomous charging devices (ACDs) remains an area of interest.

Robots are widely used in many different industries, such as the assembly or production lines to automate manufacturing procedures. In recent years, robots have been utilized in the automotive industry in an effort to automate the charging of the batteries that power electric vehicles (EVs). In order to ensure a successful connection between the socket and the connector, it is desired for robots to accurately determine the position of the EV and/or the EV socket and to align the connector in a continuously and reliable manner. Since several components may contribute to an unsuccessful plug-in and to an undesirable operational performance, further improvements are still needed in this field.

Several solutions have been proposed, such as the use of a magnetic coupling system to ensure an accurate connection between the connector and the socket. However, many of these techniques require making modifications to either the EV or to the connector which may affect the solution's scalability and accessibility in the market.

Other improvements have been made in recent years and certain ACD's currently known in the art are able to locate the position of an electric vehicle's socket and direct and plug the charger's connector without intervention of an operator or the modification of the vehicle or its charging port. These improvements rely on the use of computer vision based neural networks trained to accurately identify the socket so that the ACD can reliably complete the plug-in and

plug-out process. Devices for this purpose and methods and systems related thereto 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, PCT/EP2023/086489, from the same applicant of the present invention,
5 all of which are herein incorporated by reference. ACD devices in accordance with the present disclosure may include compliance mechanisms to support several connectors and improve safety, including but not limited to CCS-1, CCS-2, MCS, and Tesla connectors, amongst others.

An existing challenge to achieve a successful mating is ensuring the exact positioning of the
10 connector in the socket before plugging it in. This has to be done with an accuracy in a range smaller than a few millimetres and in a range smaller than a few degrees, which means that said accuracy has to be met by the charging device as it would not be feasible or practical for the vehicle to be positioned in such alignment position.

Given that autonomous charging devices comprise several components and due to the nature
15 of robot kinematics, robots may present several intrinsic inaccuracies. Said inaccuracies may be a consequence of a hardware and/or software component. In some cases, said inaccuracies may be resolved by computationally calibrating the motion model of the ACD, however, in certain instances additional hardware calibration is required which are generally undesirable and costly, especially when software updates may alter the ACD inaccuracies.
20 Additionally, many current calibration techniques are limited to offline processes, requiring the ACD to be taken out of service if a component is out of calibration and/or alignment, or when the system has to be recalibrated due to a software update. As such, it is desired for the ACD components to be calibrated in a way that enables the continuous operation and reliability of the system, reducing the need of recurrent or unexpected servicing and maintenance.

Neural networks are used for carrying out complex tasks, such as classification tasks in
25 recognizing patterns or objects in images, natural language processing, computer vision, speech recognition, bioinformatics, and other applications. In the context of the present disclosure, an ACD is provided with a computer vision unit, based on a neural network, configured to provide, or support in providing an estimation of the pose of the vehicle's socket,
30 where pose is preferably defined as the combination of position and (angular) orientation. Such neural network may be a convolutional neural network algorithm or an algorithm based on a "You Only Look Once" (YOLO) model. Based on the neural network directly, or through the use of a 3D pose estimation algorithm, the ACD may estimate the pose of the socket. Subsequently, the ACD moves the end effector supporting the charging connector towards
35 the vehicle socket in order to complete the mating process (also referred herein to as connecting or plug-in process). The output of the neural network is therefore critical for a

successful mating process. The quality of the output of a neural network depends, among other elements, on the quality of training of the neural network. However, even when the data utilized to train the neural network is deemed to be optimal, the output of the neural network may show certain inaccuracies that may result in deviations or errors in the pose estimation of the socket. The training and retraining of a neural network may help in improving the network output and subsequently the pose estimation for particular conditions or in general. However, it has been observed that updating a neural network of an ACD with a newly trained, or retrained neural network may introduce different or additional inaccuracies which may have not been previously accounted for.

- Moreover, even if an effective object pose estimation by an ACD is achieved, an unsuitable calibration or usage of the robot, or general wear and tear of the mechanical components may negatively influence the estimation of the socket pose.

It is an object of the invention to take away the disadvantages of the prior art, or at least to provide a useful alternative to them.

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.

- Document D1 WO2020142496A1 describes a method for training a robot coupled with a camera, the process comprising setting a robot or camera parameter; capturing a training image of a training object with the camera using the robot or camera parameter; changing the setting and capturing another training image and repeating such setting and capturing to obtain a plurality of training images based on different settings; training a system to recognize the training object based on the plurality of training images; and evaluating the system using pre-selected test images. This document describes the training of an industrial robot aimed at completing a manufacturing process and does not make any reference to an initial calibration compensating for the robot intrinsic inaccuracies nor a subsequent calibration related to residual inaccuracies which may be brought by a retrained neural network for socket pose detection.

SUMMARY OF THE INVENTION

- Known techniques devised for calibrating autonomous charging devices and any of their components individually or as a whole have provided limited benefits. Thus, there remains a need for improved techniques for providing an effective and autonomous process for connecting a charging connector into the socket of a vehicle.

In an embodiment, the present invention relates to a method for calibrating an autonomous charging device (ACD), the ACD comprising a camera, an end effector for supporting and moving a vehicle charging connector, a motion control unit, and a computer vision unit for socket-pose estimation, the computer vision comprising at least a baseline neural network, the motion control unit being configured to control the motion of the effector for plugging the connector into a vehicle socket using a pose estimation from the computer vision unit using an image of the socket recorded by the camera, wherein the method comprises:

- a) Obtaining a baseline inaccuracy between at least one target pose of the end effector and at least one actual pose of the end effector, wherein
 - the target pose is a pose where the motion control unit controls the end effector to move towards, and wherein the actual pose is the end pose where the end effector is effectively moved towards, and
 - the target pose is determined using an output of the baseline neural network;
- b) Adjusting the motion control unit by setting a baseline compensation function using the obtained baseline inaccuracy to compensate for the obtained inaccuracy
- c) Receiving an updated neural network for the computer vision unit;
- d) Determining a variation in a pose-estimation inaccuracy between the baseline neural network and the updated neural network; and
- e) Calibrating the motion control unit by updating the baseline compensation function based on the determined variation in pose-estimation inaccuracy.

The method according to this embodiment allows for the calibration of an ACD, or at least certain components thereof, such as the motion control, whereby the calibration unit that takes into consideration several inaccuracies of the ACD as well as inaccuracies associated to the computer vision component of the ACD. The method allows for a remote calibration of the ACD, and in particular a remote calibration of the ACD in connection with the updating of a neural network with a trained or retrained neural network.

The method according to this embodiment facilitates the deployment of a retrained neural network in order to improve the pose detection of the vehicle socket, whereby the need for a calibration of the whole ACD upon deployment of the new or retrained network may be avoided.

In an embodiment, the present invention relates to a method for updating an autonomous charging device (ACD), the ACD comprising

- an end effector for supporting and moving a vehicle charging connector,
- a motion control unit, and

- a computer vision unit for socket-pose estimation, wherein the computer vision comprises at least a baseline neural network, the motion control unit being configured to control the motion of the effector for plugging the connector into a vehicle socket using a pose estimation from the computer vision unit
- 5 wherein the motion control unit comprises a baseline compensation function compensating for an inaccuracy between an actual pose and a target pose, wherein the target pose is a pose where the motion control unit controls the end effector to move towards, and wherein the actual pose is the end pose where the end effector is effectively moved towards,
- 10 the method comprising:
 - a) Receiving an updated neural network for the computer vision unit;
 - b) Determining a variation in a pose-estimation inaccuracy between the baseline neural network and the updated neural network; and
 - c) Calibrating the motion control unit by updating the baseline compensation function
 - 15 based on the determined variation in pose-estimation inaccuracy.

In an embodiment, the present invention relates to an autonomous charging device (ACD) comprising

- an end effector for supporting and moving a vehicle charging connector;
- a camera;
- 20 - a motion control unit;
- a computer vision unit for pose estimation, comprising a baseline neural network; and wherein the motion control unit comprises a baseline compensation function compensating for an inaccuracy between an actual pose and a target pose;
- wherein the motion control unit is configured to control the motion of the end effector
- 25 for plugging the connector into a vehicle socket using a pose estimation from the computer vision unit; and
- a control device configured to:
 - Receiving an updated neural network for the computer vision unit;
 - Determining a variation in a pose-estimation inaccuracy between the baseline
 - 30 neural network and the updated neural network; and
 - Calibrating the motion control unit by updating the baseline compensation function based on the determined variation in pose-estimation inaccuracy.

In an embodiment, the present invention relates to a method for calibrating a motion control unit of multiple autonomous charging devices (ACD), said ACD's arranged in an area in which

35 operational parameters of the ACD are substantially equivalent.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is referential diagram illustrating an ACD (1) supporting the connection of a charger connector (2) into the socket (4) of an electric vehicle (5).

Figure 2 is a schematic diagram of an autonomous charging device. Depicted is a an end effector (10), a motion control unit (20), a computer vision unit (30), a control device (40) and
5 a computer system (50).

Figure 3 is a flow chart of process steps of the method according to the first embodiment of the invention.

Figure 4 is chart depicting the determination of a variation in a pose-estimation inaccuracy
10 between the baseline neural network and an updated neural network and generating an updated calibration function based on said variation in the pose-estimation inaccuracy

DETAILED DESCRIPTION OF THE INVENTION

In the following description, for purposes of explanation and not limitation, specific details are set forth, such as particular methods, steps, devices, components etc. in order to provide a
15 thorough understanding of the present invention. However, it will be apparent to one skilled in the art that the present invention may be practiced in other embodiments that depart from these specific details.

In an embodiment, the present invention relates to a method for calibrating an autonomous charging device (ACD) configured for supporting and connecting a charging connector into a
20 vehicle's charging socket based on a computer vision neural network and a motion control unit.

Autonomous charging devices

An autonomous charging device (or simply, a robot) as referred herein, may comprise several hardware and software components. In particular, the ACD may comprise an end effector for
25 supporting and moving a vehicle charging connector, a motion control unit and a computer vision unit for pose estimation, comprising at least a baseline neural network, the motion control unit being configured to control the motion of the end effector for plugging the connector into a vehicle socket using a pose estimation from the computer vision unit. The ACD may include, or be in communication with, a camera to acquire an image of the vehicle
30 socket as an input for the computer vision unit. The end effector may be a controllable actuated mechanism comprising means to support, either in a releasable manner or not, a vehicle charger connector, and is able to enable such autonomous charging process. The robot may further include one or more linkages with one or more joints, and actuators (e.g., electric

motors, stepper motors, and solenoids) coupled and operable to move the linkages in response to control or drive signals.

The ACD connecting process generally includes at least the steps of determining the pose of a vehicle charging port (including the socket cover, the socket features, the socket pins, fiducial features, markers or a combination thereof), moving a vehicle charging connector towards the vehicle charging port, connecting the charger into the vehicle socket, allowing the charging of the vehicle to take place, optionally releasing the connector from the ACD end effector, and optionally disconnecting the charging connector. The pose of the vehicle socket is preferably determined by a computer vision unit of the ACD (or which is in communication with such ACD) based on a neural network which utilizes image data from the socket to able a pose estimation by the computer vision unit, the pose including for example the position and orientation of the socket.

Due to the nature of kinematic models, the robot may be subject to several intrinsic and/or extrinsic factors which may result in an inaccurate pose estimation of the socket and/or an unsuccessful mating of the connector into the socket. Said inaccuracies may be a consequence of a hardware and/or software component of the ACD. In some cases, inaccuracies may be resolved by computationally calibrating the motion model of the ACD, to characterize its actual behaviour. However, in certain cases, additional hardware calibration may be required. ACD components which may result in one more inaccuracies include camera hardware inaccuracies, camera calibration, the ACD kinematics, slack in hardware components, compliance components, motion control, computer vision, hardware wear and tear, among others.

An ACD according to the invention is intended to be deployed to the field, such as an EV charging station where one or more charging devices are preferably positioned to facilitate the autonomous charging of such EV's. An ACD may require one or more calibration processes to achieve a suitable performance in the field, which calibration processes may take place at different situations. Such calibrations may include i) intrinsic calibration of the camera (to compensate for lens distortion), which may take place before assembly or after installation of the ACD in the field; ii) extrinsic calibration of the camera to find the exact reference frame with respect to the rest of the kinematic chain of the system may occur upon assembly or after installation in the field, i.e., a hand to eye calibration; and iii) motion control unit calibration, aimed at calibrating the motion behaviour (such as control accuracy and/or model accuracies) which may take place during or after assembly, upon commissioning of the robot or at subsequent stages.

Upon deployment of the ACD, or prior to its deployment, it is desired to adjust the motion control unit by setting a baseline compensation function using the obtained baseline inaccuracy to compensate for the obtained inaccuracy, whereby at least some, or preferably most of the possible inaccuracies, also referred to as biases or offsets, in the software or hardware components of the robot which may contribute to an undesirable execution of the mating process are compensated for. Such a setting of a baseline compensation function may take place when the ACD is assembled, or upon its installation in the field.

The ACD end effector is part of a controllable actuated mechanism also referred herein to as a manipulator or a robotic arm, which is configured to support, whether in a releasable manner or not, a vehicle charging connector and to direct the connector towards the vehicle charging port in order to complete the plug-in and/or plug-out process.

In accordance with the invention, sensors may be mounted in or around the ACD and be used to capture data of the vehicle, the vehicle socket or its surroundings. Multiple sensors may be mounted on the same ACD and may be of various types to gather several types of part/object information. Sensors include sensors collecting data, such as a 2D or 3D camera that is configured to gather images, video and/or audio. However, such data may also be obtained from sensors positioned outside of the ACD system. Sensors in accordance with the present disclosure further including force, light, wind, geographic position and orientation, temperature and pressure sensors, as well as any combinations thereof. Sensors in accordance with the invention may also provide date and time on which the data was captured.

Socket pose estimation

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 object's pose may include three dimensions of information characterizing the object's rotation with respect to the camera perspective or camera coordinate system. Alternately, or additionally, an object's pose may include three dimensions of information characterizing the object's translation with respect to the camera perspective or camera coordinate system.

In the context of the present disclosure, the pose determination is made of an electric vehicle socket but is not limited thereto. Preferably, the pose of an electric vehicle charging port (also referred to as socket) 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). However, in some embodiments, the pose is a 6D pose where the position is defined by a 3D Cartesian position and the orientation is defined by a roll, pitch, and yaw of the socket.

Determination of the electric vehicle socket pose is useful for describing the pose and orientation of the charging port relative to a camera position of the ACD in order to direct an EV connector towards a charging port and completing the plug-in process. By obtaining a determination of the charging port relative to the camera pose and by conducting an eye-to-hand calibration, the motion control unit may direct the end effector to move towards the socket estimated pose.

The pose of an object 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.

Computer vision unit neural network

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. Preferably, a neural network may be trained to determine the pose through an analysis of one or more images. The estimated socket pose may include 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 algorithm may determine the pose of the socket with respect to the camera.

The computer vision unit is based on, or may comprise, a neural network. In some embodiments, the computer vision unit is configured to host one or more computer vision neural networks, also referred herein simply as, a neural network. The computer vision unit can be in communication with, or host, a computer vision training module and/or a computer vision testing module. The training module and/or testing module may be hosted independently from the computer vision unit. In some embodiments, the computer system further may comprise an edge computer hosting the training module and/or testing module, which can run machine learning algorithms based on collected data to shape the knowledge of neural network for a general or a case specific application. The computer vision neural network may be any kind of neural network that may be used in image processing. For example, the neural network may be a feed-forward neural network, a regulatory feedback neural network, a convolutional neural network, a recurrent neural network.

Improving the robustness of the computer vision component, which is a component able to determine the relative position and orientation of the charging port is a key task in to increase process performance. Given that the performance of the computer vision component is

generally dependent on the neural network that it is built on, it is desirable to provide the computer vision unit with a robust neural network suited to the ACD system.

In certain embodiments of the present disclosure, pose determination of a vehicle or a vehicle charging port may be done directly by a neural network. In certain embodiments, a neural network may be trained to determine the location of geometric features of the socket, to be used as fiducial marker, based on which an algorithm, such as a perspective-n-point algorithm like solvePnP or RANSAC (Random Sample Consensus) , can estimate the pose of the socket. This may make use of a single, or multiple images.

A neural network's training process normally determines the quality of the network output. Training and testing a neural network may include several steps. Initially, a large dataset of images capturing various scenarios relevant to the ACD's operation, such as different lighting conditions, socket orientations, and environmental variations, is collected. These images are then annotated with ground truth pose information, which serves as the reference for training the neural network.

The training process typically involves feeding these annotated images into the neural network and adjusting its internal parameters iteratively to minimize the difference between the predicted poses and the ground truth poses. This adjustment is achieved through optimization algorithms like stochastic gradient descent, where the network learns to extract relevant features from the images and make accurate pose estimations.

To evaluate the performance of the trained neural network, a separate dataset, distinct from the training data, may be used for testing. This testing dataset helps assess how well the network generalizes to unseen data. Various metrics such as precision, recall, and mean squared error may be computed to quantify the network's performance.

Additionally, techniques like cross-validation may be employed to ensure that the network's performance is consistent across different subsets of the data. Cross-validation involves splitting the dataset into multiple subsets, training the network on one subset, and testing it on the remaining subsets, rotating this process to cover all possible combinations. This helps detect overfitting, where the network performs well on the training data but fails to generalize to new data.

Furthermore, fine-tuning and optimization strategies may be applied to enhance the network's performance. This may involve adjusting hyperparameters such as learning rate, network architecture, or regularization techniques to achieve better pose estimation results.

Generally, large amounts of training data are collected and manually or automatically annotated. In order to improve performance of the ACD, it is desired to retrain the neural

network based on newly collected data, or data that is regarded to be more suitable for a particular ACD or group of ACD's.

The training and retraining of a neural network may help in improving the network output and subsequently the pose estimation. In some cases, it is expected that a neural network may present certain inaccuracies in the detection of a pose, for example, when the network is trained for pose detection of a new socket where the amount or quality of training data is insufficient. In some cases, the deployment of a new neural network into an ACD (also referred herein as neural network update or updating) may introduce additional inaccuracies, also referred to as offset, which may have not been previously accounted for. Likewise, the deployment or update of a new neural training may reduce or change the magnitude of inaccuracies of an existing baseline neural network. In the context of the invention, it may be assumed that the computer vision unit and/or its neural network may always be subject to inaccuracies, meaning that they may not always determine a ground truth. In such a case, a proper comparison between a baseline neural network and an updated neural network determines a variation in their inaccuracies.

As used herein, the term baseline neural network is used when referring to an initial neural network model deployed within the computer vision unit of the ACD. This baseline neural network may serve as the baseline for socket-pose estimation, providing the initial framework for determining the relative position and orientation of the charging port. As used herein, the term trained neural network is employed when describing a neural network that has undergone one or more trainings and possibly subsequent retraining processes to enhance its performance and adaptability within the ACD system.

Based on the foregoing, in several embodiments of the present disclosure, the invention may comprise determining a variation in a pose-estimation inaccuracy between the baseline neural network and the updated neural network; and calibrating the motion control unit by updating the baseline compensation parameter based on the determined variation in pose-estimation inaccuracy, wherein the motion control unit is calibrated when the determined variation exceeds a predetermined threshold

The ACD preferably may comprise, or is in network communication with, a computer system, suitable to control any of the components of the ACD, including but not limited to the one or more end effectors, one or more cameras, one or more computer vision units, one or more motion control units, among others. The computer system may be any type of suitable computer system, such as an edge computer that is able to control either directly or via a controller, one or various components of the ACD.

The ACD workspace represents a three-dimensional space in which the robot may operate and move, although in certain implementations the workspace may represent a two-dimensional space. Preferably, the workspace refers to the complete range of poses where the end effector of the ACD may be moved to. The workspace may vary or may be adapted
5 depending on the type of ACD or its specific configuration.

The robot may comprise, or is in communication with, a motion control unit, which may further comprise a motion planner, the motion control unit configured to dynamically produce motion plans for the end effector based on the determined socket pose and the end effector determined pose. The motion control preferably may comprise an algorithm for controlling the
10 motion of the end-effector supporting the charging connector.

ACD calibration

In accordance with the present disclosure, performance, reliability and/or accuracy of the plug-in process can be influenced by the individual behaviour of various components of the ACD, such as the performance of the computer vision component, mechatronics, system and
15 component calibration (such as a camera's intrinsic and extrinsic calibration), hand-eye calibration of the relative position of the camera and the end-effector and/or the connector, wear and tear, amongst others. Advantageously, the ACD reliability and autonomous operation may be improved by a suitable calibration of the motion control unit, wherein said calibration takes into consideration some, or preferably all components of the ACD which may
20 contribute to an undesirable performance or process inaccuracy. By performing a calibration of the motion unit, it is possible to compensate for the existing and newly introduced accuracies in the system. Preferably, the calibration of the motion control unit takes into consideration prior calibrations made in the ACD. Within the scope of the present invention, the motion control unit may be calibrated by setting a baseline compensation parameter and by
25 updating said baseline compensation parameter preferably when an updated neural network for the computer vision unit is received and is intended to be deployed into the ACD computer vision unit. Such adjusting and/or calibration may be made by a computer system configured to adjust the algorithm for controlling the motion of the end-effector.

In a first embodiment, a method for calibrating an autonomous charging device (ACD), is
30 described, the ACD comprising an end effector for supporting and moving a vehicle charging connector, a motion control unit, and a computer vision unit for socket-pose estimation, the computer vision comprising at least a baseline neural network, the motion control unit being configured to control the motion of the effector for plugging the connector into a vehicle socket using a pose estimation from the computer vision unit.

Figure 3 shows a schematic illustration of an exemplary embodiment of the method according to the invention as a flow chart.

The method starts with step 100 obtaining a baseline inaccuracy between at least one target pose of the end effector and at least one actual pose of the end effector, wherein the target pose is a pose where the motion control unit controls the end effector to move towards, and wherein the actual pose is the end pose where the end effector is effectively moved towards, and the target pose is determined using an output of the baseline neural network;

The method continues with step 110 adjusting the motion control unit by setting a baseline compensation function using the obtained baseline inaccuracy to compensate for the obtained inaccuracy;

The method continues with step 120 receiving an updated neural network for the computer vision unit;

The method continues with step 130 determining a variation in a pose-estimation inaccuracy between the baseline neural network and the updated neural network

The method continues with step 140 Calibrating the motion control unit by updating the baseline compensation function based on the determined variation in pose-estimation inaccuracy.

In more detail, the method in accordance with the first embodiment may comprise

- a) Obtaining a baseline inaccuracy between at least one target pose of the end effector and at least one actual pose of the end effector, wherein
 - the target pose is a pose where the motion control unit controls the end effector to move towards, and wherein the actual pose is the end pose where the end effector is effectively moved towards, and
 - the target pose is determined using an output of the baseline neural network;
- b) Adjusting the motion control unit by setting a baseline compensation function using the obtained baseline inaccuracy to compensate for the obtained inaccuracy

Baseline inaccuracy

The baseline inaccuracy between a target pose and the actual pose may be the result of the addition of some or all inaccuracies introduced by one or more components leading up to bringing the connector into an assumed pose. Said inaccuracy may be a representation of a particular value, such as a specific vector and a magnitude and may also be a value or set of values that vary throughout a certain timeframe, i.e., varying vectors and magnitudes. Said inaccuracy may be defined as a set of coordinates including translation and rotation coordinates representing the difference between a target pose and the actual pose. In some

cases, the baseline inaccuracy may be defined as the size of the offset between a target pose of the end effector and an actual pose.

The baseline inaccuracy comprises at least one or more individual inaccuracies. The baseline inaccuracy includes at least one of an inaccuracy of the baseline neural network, a pose-
5 estimation inaccuracy, an inaccuracy due to an ACD hardware component, an inaccuracy due to an ACD software component, and an inaccuracy in the motion control unit. A baseline inaccuracy related to the hardware component may include at least one of a camera hardware inaccuracy, inaccuracies in manufacturing and assembly of structural and/or moveable components, inaccuracies in control of moveable components, slack in moveable
10 components, compliant deformation, wear and tear of ACD structural components, compared to the respective representation of these components in the control algorithm of the system. The baseline inaccuracy may be a determination of the overall system inaccuracy as it takes into consideration a multicomponent set of individual inaccuracies. Preferably, the magnitude and origin of each of said individual inaccuracies may be identified.

15 The target pose is preferably determined by estimating the pose of a vehicle socket by means of the computer vision unit of the ACD, and by instructing the ACD to move the end effector towards such estimated pose. Any inaccuracy in the pose estimation by the computer vision unit shall be reflected in the socket pose estimation. Both the target pose and the actual pose may be defined as a set of coordinates including translation and rotation coordinates.

20 The target pose may be a pose where the motion control unit controls the end effector to move towards, and the actual pose may be the end pose where the end effector is effectively moved towards. Due to hand to eye calibration, the ACD and the motion control unit are able to determine the relative pose of the end effector and/or the charging connector to the camera and use a hand to eye transformation matrix to move the end effector accordingly. In some
25 cases, the actual pose is equal to the target pose. In such a case, a successful mating process is expected. In some cases, the target pose is insignificantly unequal to the actual pose. In such a case, a successful mating may also be expected given the complaint nature of the ACD or the presence of guiding surfaces in the vehicle socket. In some cases, the target pose is significantly unequal to the actual pose, which may be referred to herein as a baseline
30 inaccuracy. In such a case, an unsuccessful mating may be expected.

The baseline inaccuracy may be determined by instructing the ACD to move the charging connector to a target pose and measuring the offset, i.e., the size of the offset, between the target pose and the actual pose. Preferably, the baseline inaccuracy may be obtained by instructing the ACD to move the charging connector to the at least one target pose and
35 measuring the translational and rotational differences between the at least one target pose

and the respective at least one actual pose. In some cases, the baseline inaccuracy is obtained by measuring the translational and rotational differences between a plurality of target poses and their respective actual poses. In some cases, the baseline inaccuracy may be obtained by a prediction function from one or more previous offset determinations. In some cases, the baseline inaccuracy may be obtained by measuring a rotational and/or translational compliance motion incurred by the charging connector due to a self-aligning component of the charging connector and/or a guiding surface of the socket when connecting into the socket, wherein the compliance motion refers to the movement or displacement of the self-aligning component due to external forces or loads. A compliance motion may include at least one of a deflection and deformation of a compliant component, wherein deflection refers to the bending or displacement of a component under load without a change in its shape or size and wherein deformation, involves a change in the shape or size of the component under load, such as stretching, compressing, or twisting. In some cases, the baseline inaccuracy is obtained by receiving sensor data from a sensor including a force sensor, a torque sensor, a force and torque sensor, one or more camera's, one or more distance sensors, a motion-capture system, or a combination thereof.

The baseline inaccuracy may be obtained by iteratively determined the baseline inaccuracy for different estimate poses until the iteration step no longer results in a significant difference in the obtained baseline inaccuracy. The baseline inaccuracy may be obtained by iteratively determining the baseline inaccuracy for different estimate poses until the iteration step no longer results in a significant difference in the obtained baseline inaccuracy, wherein the different estimate poses cover a majority of the poses within a workspace of the ACD.

Baseline compensation function

Once the baseline inaccuracy is obtained, the method may comprise adjusting the motion control unit by setting a baseline compensation function to compensate for the obtained inaccuracy, wherein the setting of the baseline compensation function utilizes the obtained baseline inaccuracy. Adjusting the motion control unit may enable the actual pose to be close or closer to the target pose, and the target pose to be a pose accurate enough to facilitate a successful insertion and extraction of the charging connector.

The adjusting of the motion control unit by setting a baseline compensation function may include at least one offset assigned to at least one of three-dimensional space coordinates, and wherein the motion control unit is adjusted by setting such baseline compensation function to compensate for the obtained inaccuracy. Examples of such at least one offset include a rotation offset of a certain magnitude and a translation offset of a certain magnitude, where such offset allows compensating for the obtained inaccuracy. The setting of a baseline

compensation function may include assigning at least one offset to the motion control unit to compensate for the obtained inaccuracy, wherein said offset includes a rotation offset, a translation offset or a combination thereof. In some cases, it may include the assignment of an offset to at least one, at least two, at least three, at least four, at least five or at least six

5 degrees of freedom to the motion control unit to compensate for the obtained inaccuracy. The setting of a baseline compensation function may include assigning at least one, two or three rotational degrees of freedom, and an offset to at least one, two or three translational degrees of freedom to the motion control unit to compensate for the obtained inaccuracy. This way, when the motion control unit is operated, it takes into account the assigned offsets, thereby

10 compensating for the obtained inaccuracies. For instance, if the unit is intended to move in a straight line along a certain axis but exhibits a slight deviation due to inherent inaccuracies, the baseline compensation function may adjust the motion accordingly by applying the assigned offsets. Similarly, if there is a rotational misalignment during a motion, the compensation function may correct it by applying the designated rotation offset. As used

15 herein, the term offset denotes a predetermined adjustment applied to the motion control unit of the ACD to compensate for the obtained inaccuracies. Such offsets represent corrective measures implemented within the motion control unit to ensure that the actual pose closely aligns with the target pose, facilitating successful insertion and extraction of the charging connector into the socket.

20 The baseline compensation function may include at least one of a corrective qualitative and quantitative instruction which allows the ACD to achieve a successful plug-in of the connector into the vehicle socket. In some cases, the baseline compensation function may be generated by using recorded position values of the charging connector. In some cases, the baseline compensation function may be a function of the pose or range of poses of the end effector

25 within the ACD workspace where the baseline inaccuracy is determined. A baseline compensation function may be selected from one or more of a black- grey- or whitebox model and a parameterized or non-parameterized model.

The baseline compensation function may include a combination of calibrations of individual components of the ACD, and may additionally, or alternatively, include an overall calibration

30 function to compensate for any remaining inaccuracies, such that the ACD is able to successfully insert and extract connectors respectfully into and from EVs. In some cases, the baseline compensation function may comprise at least one subfunction, wherein such at least one subfunction compensates for the obtained baseline inaccuracy. In some cases the baseline compensation function comprises at least one baseline compensation subfunction,

35 each compensating for at least one of: an inaccuracy of the baseline neural network, a pose-estimation inaccuracy, an inaccuracy due to an ACD hardware component, an inaccuracy due

to an ACD software component, an inaccuracy in the motion control unit, or combinations thereof. In some cases, the baseline compensation function may comprise at least one subfunction, wherein such at least one subfunction compensates for at least one of an inaccuracy of the computer vision output, an inaccuracy of the baseline neural network, a
5 pose-estimation inaccuracy, an inaccuracy due to an ACD hardware component, an inaccuracy due to an ACD software component, and an inaccuracy in the motion control unit. In some cases, the baseline compensation function includes a subfunction isolated to one of the pose-estimation output or the computer vision output, i.e., the baseline compensation function comprises at least one subfunction and wherein such subfunction compensates only
10 for the pose-estimation output or the computer vision output. In such a case, updating the baseline compensation function based on a determined variation in pose-estimation inaccuracy may be advantageously made taking only into consideration such pose-estimation output or the computer vision output without necessarily having to take other subfunctions into account.

15 The baseline compensation function may be set as an overarching system calibration function or as a function to calibrate the ACD system or subsystems thereof. A baseline compensation function may be selected from one or more of a function to alter a signal value, for example using a constant offset, or a linear, non-linear or polynomial function to describe behaviour dependent on time, space or dependent on other parameters, where these functions may have
20 multiple in- and outputs. Other specific examples may also be look-up tables, with or without inter- or extrapolation to find values in between the entries.

In some cases, when the baseline inaccuracy exceeds a predetermined threshold, such as when the target pose is significantly unequal to the actual pose, the method may include adjusting the motion control unit by setting a baseline compensation function using the
25 obtained baseline inaccuracy to compensate for the obtained inaccuracy. In some cases, the motion control unit is adjusted when the baseline inaccuracy exceeds a threshold of 0.1 mm or a 0.1 degree offset in cartesian space.

The actions described herein, namely, the obtaining or determination of the baseline inaccuracy, setting a baseline compensation function, and adjusting the motion control unit
30 may be performed by an ACD controller, by an ACD operator and/or by a controller in a remote manner. In the context of the invention, the term "obtaining" may refer generally to retrieving or receiving information. In the context of the invention, the term "determining" may refer generally to measuring either qualitatively or quantitatively.

The method may also comprise comparing the determined baseline inaccuracy to a dynamic
35 threshold, and calibrating the motion control unit when the baseline inaccuracy exceeds the

dynamic threshold. Preferably, the dynamic threshold is a function of the pose of end effector within the workspace. Within the end effector workspace, the end effector may be require to exercise different displacement or rotational motions. As such, within certain areas of the end effector workspace, an inaccuracy may be expected to be greater or smaller than in other areas. The dynamic threshold may be a threshold that is dependent on the pose of the end effector.

Pose-estimation variation

The training, retraining, updating and/or deployment of a neural network may help in improving the network output and as such, pose-estimation, however, it has been observed that the updating of a new neural network into the computer vision unit may change the magnitude of existing inaccuracies, or even introduce additional or different inaccuracies not considered by the baseline compensation function. Advantageously, the present invention allows for a determination of a variation in a pose-estimation inaccuracy between a baseline neural network and an updated neural network so that the baseline compensation function may be updated accordingly and enable a successful connection process upon updating and deployment of the neural network. In other words, the present invention allows compensating the influence of the difference in pose-estimation inaccuracy of the updated neural network on the motion control unit.

In particular, the method of the present invention further may comprise:

- c) Receiving an updated neural network for the computer vision unit;
 - d) Determining a variation in a pose-estimation inaccuracy between the baseline neural network and the updated neural network; and
 - e) Calibrating the motion control unit by updating the baseline compensation function based on the determined variation in pose-estimation inaccuracy.
- Calibrating the baseline compensation function based on the determined variation in pose-estimation inaccuracy may preferably enable the motion control unit to continue to achieve a successful plug-in. The calibrating of the motion control is preferably made by updating the baseline compensation function, which allows for the calibration of the motion control unit or an output thereof.
- The variation in the pose-estimation inaccuracy may be determined by several means, including measuring the difference in the inaccuracy of the pose-estimation output of the baseline neural network and the updated neural network against a benchmark dataset comprising a plurality of images based on which an ACD has plugged in or would likely plug in successfully.

Additionally, or alternatively, the variation in the pose-estimation inaccuracy may be determined by subtracting the output of the updated neural network from the output of the baseline neural network over the benchmark dataset of images.

5 Additionally, or alternatively, the variation in the pose-estimation inaccuracy may be the mean of the difference of the output of the baseline neural network and the output of the retrained neural network over the benchmark dataset of images.

Additionally, or alternatively, the variation in the pose-estimation inaccuracy may include the mean of values resulting from subtracting the output of the updated neural network from the output of the baseline neural network.

10 Additionally, or alternatively, the variation in the pose-estimation inaccuracy may be determined by comparing an absolute socket-pose estimation error function of the updated neural network with respect to the ground truth with the absolute socket-pose estimation error function of the baseline neural network with respect to the ground truth, wherein the socket-pose estimation error function may be determined by comparing the output of the respective
15 neural network with the ground-truth measurements. In accordance with the invention, ground-truth may refer to manually labelled data that represents the correct classification or annotation of the socket or features thereof present in the images of the socket.

Additionally, or alternatively, images in the benchmark dataset may include means to determine a ground-truth measurement of the socket pose with respect to the camera, wherein
20 the means to determine the ground-truth may comprise at least one fiducial marker placed at a known position with respect to the socket.

The variation in the pose-estimation inaccuracy may be defined as a set of coordinates including at least one of a translation and rotation coordinates representing the variation in the pose-estimation inaccuracy.

25 The baseline compensation function may be updated by adding or subtracting from the baseline compensation function, the determined variation in the pose-estimation inaccuracy. The determined variation may additionally, or alternatively, be added to subtracted from the pose-estimate of the computer vision module, thereby adjusting the output of the motion control unit. Similarly, the baseline compensation function may be updated by adding the
30 variation in the pose estimation inaccuracy, such as the mean of values when subtracting the output of the updated neural network from the output of the baseline neural network, to the pose-estimate of the computer vision module, thereby adjusting the output of the motion control unit.

In some cases, the baseline compensation function may be updated by adding a six degrees of freedom constant offset to the output of the computer vision module, wherein the offset is determined by subtracting the six degrees of freedom output of the computer vision module when running a benchmark dataset with the updated neural network from the six degrees of freedom output of the computer vision module when running a benchmark dataset with the baseline neural network. In some cases, the motion control unit is calibrated by updating the baseline compensation function wherein at least one subfunction of the baseline compensation function is updated using the variation in a pose-estimation inaccuracy.

In some cases, the baseline compensation function may be updated by determining a six degrees of freedom offset function and adjusting the output of the computer vision module using said offset function, wherein the offset function is obtained by determining the updated neural network's absolute estimation error based on a ground-truth measurement. In such a case, the updated neural network's absolute estimation error may be determined by placing a fiducial marker on a known position relative to an EV socket, estimating the pose of both the socket and the fiducial marker in one image from several recording positions, using the estimate of the fiducial marker as a ground truth, estimating the error of the socket-pose by means of the ground truth, averaging the estimation error over the several recording positions, and determining a six degrees of freedom offset function based on an absolute estimation error. Preferably, in such a case, an average of the absolute estimation error is obtained based on the averaged estimation error over the several recording positions.

Advantageously, the motion control unit may be calibrated from a remote device via a communication device, and wherein the remote device compares the variation in the pose estimation with an optimal variation range from a database of historical determinations, and adjusts the threshold based on said optimal variation. In some cases, the calibrating of the motion control unit is a re-calibration.

Preferably, the method of the invention may comprise deploying the updated neural network into the computer vision unit. In some cases, the neural network is deployed provided that an improvement in the pose estimation is observed between the baseline neural network and the updated neural network.

The actions described herein, namely, the receiving an updated neural network, determining a variation in a pose-estimation inaccuracy and calibrating the motion control unit may be performed by an ACD controller or control device, by an ACD operator and/or by a controller or control device in a remote manner.

In another embodiment, the present invention relates to a method for updating an autonomous charging device (ACD), the ACD comprising

- an end effector for supporting and moving a vehicle charging connector,
- a camera
- a motion control unit, and
- a computer vision unit for socket-pose estimation,

5 wherein the computer vision comprises at least a baseline neural network, the motion control unit being configured to control the motion of the effector for plugging the connector into a vehicle socket using a pose estimation from the computer vision unit using an image of the socket recorded by the camera, wherein the motion control unit comprises a baseline compensation function

10 compensating for an inaccuracy between an actual pose and a target pose, wherein the target pose is a pose where the motion control unit controls the end effector to move towards, and wherein the actual pose is the end pose where the end effector is effectively moved towards,

15 wherein the method comprises:

- a) Receiving an updated neural network for the computer vision unit;
 - b) Determining a variation in a pose-estimation inaccuracy between the baseline neural network and the updated neural network; and
 - c) Calibrating the motion control unit by updating the baseline compensation function
- 20 based on the determined variation in pose-estimation inaccuracy.

In another embodiment, the present invention relates to an autonomous charging device comprising:

- an end effector for supporting and moving a vehicle charging connector;
- a camera;
- 25 – a motion control unit;
- a computer vision unit for pose estimation, comprising a baseline neural network; and
- wherein the motion control unit is configured to control the motion of the end effector for plugging the connector into a vehicle socket using a pose estimation
- 30 from the computer vision unit using an image of the socket recorded by the camera; wherein the motion control unit comprises a baseline compensation function compensating for an inaccuracy between an actual pose and a target pose; and
- a control device

characterized in that the control device is configured to:

- 35 – receive an updated neural network for the computer vision unit;

- determine a variation in a pose-estimation inaccuracy between the baseline neural network and the updated neural network; and
- calibrate the motion control unit by updating the baseline compensation parameter based on the determined variation in pose-estimation inaccuracy.

5 The ACD may further comprise a camera configured to record at least one image of a vehicle charging socket, whereby the image is used as input for the computer vision unit.

The ACD may further comprise a computer system in communication with the motion control unit the computer system comprising a storage unit configured to store one or more of a determination of a baseline inaccuracy, a baseline compensation parameter and/or an
10 adjusted compensation parameter.

The control device may be further configured to obtain a baseline inaccuracy between a target pose of the end effector and an actual pose of the end effector, and generating a baseline compensation function based on said baseline inaccuracy, wherein the target pose is determined using an output of the computer vision baseline neural network; and to adjust the
15 motion control unit, or an output thereof, by setting a baseline compensation parameter using the baseline compensation function to compensate for the obtained inaccuracy

Exemplary realization

In an exemplary realization, a variation in a pose estimation offset between a baseline neural network and a retrained neural network is conducted by training two networks using a general
20 dataset comprising 3409 images of a CCS2 socket. The two networks are individually trained using a dataset consisting of a 50/50 split of the general dataset and by making a subsequent 80/10/10 for each split for the training/testing/validation, respectively. In parallel, a benchmark dataset of 141 recorded images is generated with validated poses and the trained networks are used to generate a pose estimation of the 141 images of the benchmark dataset. The
25 resulting pose estimation pairs were compared and their differences visualized. Figure 4 depicts an histogram representing the observed offsets between the two networks, both for translation and rotation differences. It was observed that majority of the translation and rotation offsets, i.e., variation in a pose estimation offset between the baseline neural network and a retrained neural network, fall within a certain identifiably range, based on which the variation
30 in a pose-estimation inaccuracy between the baseline neural network and the updated neural network is determined. The motion control unit may be calibrated by updating the baseline compensation function based on the determined variation in pose-estimation inaccuracy. In this exemplary embodiment, the variation in a pose-estimation inaccuracy is the mean of the difference of the output of the baseline neural network and the output of the retrained neural
35 network over the benchmark dataset of images.

The experimental results demonstrate that upon applying the calibrating method of the present invention, the ACD is able to make an estimation of the socket pose and account for extrinsic and intrinsic accuracies, including those related to the update of a neural network for the computer vision unit.

- 5 Advantageously, the calibrated ACD is able to estimate the pose of the socket and complete the mating process across a large area of the ACD working space. Advantageously calibrated kinematic parameters achieved proper accuracy in the defined areas, and the robot's accuracy in the nearby areas will not change dramatically. Therefore, the ACD can move in a larger workspace and still make relatively accurate predictions.
- 10 For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the embodiments illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended. Any alterations and further modifications in the described embodiments, and any further applications of the principles of the invention as described
- 15 herein are contemplated as would normally occur to one skilled in the art to which the invention relates

In some instances, one or more components may be referred to herein as "configured to," "configured by," "configurable to," "operable/operative to," "adapted/adaptable," "able to," "conformable/conformed to," etc. Those skilled in the art will recognize that such terms (for

20 example "configured to") generally encompass active-state components and/or inactive-state components and/or standby-state components, unless context requires otherwise.

Conditional language used herein, such as, among others, "can," "could," "might," "may," "e.g." and the like, unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other

25 embodiments do not include, certain features, elements and/or steps. Thus, such conditional language is not generally intended to imply that features, elements and/or steps are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without author input or prompting, whether these features, elements and/or steps are included or are to be performed in any particular embodiment.

30 The terms "comprising," "including," "having" and the like, are synonymous and are used inclusively, in an open-ended fashion, and do not exclude additional elements, features, acts, operations, and so forth. Also, the term "or" is used in its inclusive sense (and not in its exclusive sense) so that when used, for example, to connect a list of elements, the term "or" means one, some, or all of the elements in the list. In addition, the articles "a," "an," and "the"

35 as used in this application and the appended claims are to be construed to mean "one or more"

or “at least one” unless specified otherwise. As used herein, a phrase referring to “at least one of” or “and/or” a list of items refers to any combination of those items, including single members.

Similarly, while method steps may be depicted in the drawings in a particular order, it is to be
5 recognized that such method steps need not be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. Further, the drawings may schematically depict one more example processes in the form of a flowchart. However, other operations that are not depicted can be incorporated in the example methods and processes that are schematically illustrated. For example, one or more additional
10 operations can be performed before, after, simultaneously, or between any of the illustrated operations. Additionally, the operations may be rearranged or reordered in other implementations. In certain circumstances, multitasking and parallel processing may be advantageous.

It will be appreciated that the detailed description set forth above is merely illustrative in nature
15 and variations that do not depart from the gist and/or spirit of the claimed subject matter are intended to be within the scope of the claims. Such variations are not to be regarded as a departure from the spirit and scope of the claimed subject matter.

CLAIMS

1. A method for calibrating an autonomous charging device (ACD), the ACD comprising a camera, an end effector for supporting and moving a vehicle charging connector, a motion control unit, and a computer vision unit for socket-pose estimation, the computer vision comprising at least a baseline neural network, the motion control unit being configured to control the motion of the effector for plugging the connector into a vehicle socket using a pose estimation from the computer vision unit using an image of the socket recorded by the camera,
- 5
- characterized in that the method comprises:
- 10
- a) Obtaining a baseline inaccuracy between at least one target pose of the end effector and at least one actual pose of the end effector, wherein
- the target pose is a pose where the motion control unit controls the end effector to move towards, and wherein the actual pose is the end pose where the end effector is effectively moved towards, and
 - 15 – the target pose is determined using an output of the baseline neural network;
- b) Adjusting the motion control unit by setting a baseline compensation function to compensate for the obtained baseline inaccuracy;
- c) Receiving an updated neural network for the computer vision unit;
- 20
- d) Determining a variation in a pose-estimation inaccuracy between the baseline neural network and the updated neural network; and
- e) Calibrating the motion control unit by updating the baseline compensation function based on the determined variation in pose-estimation inaccuracy.
2. Method according to claim 1, wherein setting a baseline compensation function includes assigning at least one offset to the motion control unit to compensate for the obtained inaccuracy, wherein said offset includes a rotation offset, a translation offset or a combination thereof.
- 25
3. Method according to claim 1, wherein the baseline inaccuracy includes at least one of an inaccuracy of the baseline neural network, a pose-estimation inaccuracy, an inaccuracy due to an ACD hardware component, an inaccuracy due to an ACD software component, and an inaccuracy in the motion control unit.
- 30
4. Method according to anyone of the preceding claims, wherein the baseline compensation function comprises at least one baseline compensation subfunction, each compensating for at least one of: an inaccuracy of the baseline neural network, a pose-estimation inaccuracy, an inaccuracy due to an ACD hardware component, an
- 35

inaccuracy due to an ACD software component, an inaccuracy in the motion control unit, or combinations thereof.

5. Method according to claim 4, wherein the at least one subfunction compensates only for a pose-estimation inaccuracy.
- 5 6. Method according to claim 4, wherein the at least one subfunction includes assigning at least one of: a rotation offset and a translation offset to the motion control unit to compensate for the obtained inaccuracy
7. Method according to anyone of the preceding claims, wherein the baseline compensation function is selected from at least one or more of a black- grey- or white-
10 box model, wherein the model is a parameterized or non-parameterized model, and wherein the baseline compensation function is set as an overarching system calibration function or as a function to calibrate the ACD or subsystems thereof, or a combination thereof.
8. Method according to anyone of the preceding claims, wherein the baseline inaccuracy
15 is obtained by measuring a rotational and/or translational compliance motion incurred by the charging connector due to a self-aligning component of the charging connector and/or a guiding surface of the socket when connecting into the socket, wherein the compliance motion includes at least one of a deflection and deformation of a compliant component.
- 20 9. Method according to anyone of the preceding claims, wherein the baseline inaccuracy is obtained by instructing the ACD to move the charging connector to the at least one target pose and measuring the translational and rotational differences between the at least one target pose and the respective at least one actual pose, wherein the baseline inaccuracy is obtained by measuring the translational and rotational differences
25 between a plurality of target poses and their respective actual poses.
10. Wherein the baseline inaccuracy is obtained by iteratively determining the baseline inaccuracy for different target and respective actual poses until the iteration step no longer results in a significant difference in the obtained baseline inaccuracy, wherein the different estimate poses cover a majority of the poses within a workspace of the
30 ACD.
11. Method according to anyone of the preceding claims, wherein the baseline compensation function includes at least one of a corrective qualitative and quantitative instruction that allows the ACD to achieve a successful plug-in of the connector into the vehicle socket.

12. Method according to anyone of the preceding claims, wherein the baseline compensation function is set to obtain an acceptable difference between the target pose and the actual pose, and/or to adjust the target pose, such that the ACD is able to successfully insert and extract a vehicle charging connector into the vehicle socket.
- 5 13. Method according to anyone of the preceding claims, wherein the baseline compensation function includes at least one offset assigned to at least one of three-dimensional space coordinates, and wherein the motion control unit is adjusted by assigning said compensation function to the motion control unit.
- 10 14. Method according to anyone of the preceding claims, wherein the baseline compensation function is a function of the pose of end effector within the workspace when the baseline inaccuracy is determined.
- 15 15. Method according to anyone of the preceding claims, wherein the variation in the pose-estimation inaccuracy is determined by measuring the difference in the inaccuracy of the pose-estimation output of the baseline neural network and the updated neural network against a benchmark dataset comprising a plurality of images based on which an ACD has plugged in or would likely plug in successfully.
16. Method according to claim 15, wherein images in the benchmark dataset contain means to determine a ground-truth measurement of the socket pose with respect to the camera.
- 20 17. Method according to claim 15, wherein the benchmark dataset comprises a plurality of images annotated with at least one ground truth label.
18. Method according to anyone of the preceding claims, wherein the variation in the pose-estimation inaccuracy is determined by subtracting an output of the updated neural network from an output of the baseline neural network.
- 25 19. Method according to anyone of the preceding claims, wherein the variation in the pose-estimation inaccuracy is a mean of the difference of an output of the baseline neural network and an output of the retrained neural network over a benchmark dataset of images.
- 30 20. Method according to anyone of the preceding claims, wherein the variation in the pose-estimation inaccuracy is determined by comparing an absolute socket-pose estimation error function of the updated neural network with respect to the ground truth with the absolute socket-pose estimation error function of the baseline neural network with respect to the ground truth, wherein the socket-pose estimation error function is

determined by comparing the output of the respective neural network with the ground-truth measurement.

21. Method according to claim 20, wherein the means to determine the ground-truth comprise at least one fiducial marker placed at a known position with respect to the socket.
22. Method according to anyone of the preceding claims, wherein the baseline compensation function is updated by adding the variation in the pose-estimation inaccuracy to the pose-estimate of the computer vision module.
23. Method according to anyone of the preceding claims, wherein the baseline compensation function is updated by using an absolute pose-estimation error function of the updated neural network, instead of adjusting the baseline compensation function.
24. Method according to anyone of the preceding claims, wherein the baseline compensation function is updated by adding a six degrees of freedom constant offset to the output of the computer vision module, wherein the offset is determined by subtracting the six degrees of freedom output of the computer vision module when running a benchmark dataset with the updated neural network from the six degrees of freedom output of the computer vision module when running a benchmark dataset with the baseline neural network.
25. Method according to anyone of the preceding claims, wherein the baseline compensation function is updated from a remote device via a communication device, and wherein the remote device compares the variation in the pose-estimation inaccuracy with an optimal variation range from a database of historical determinations, and adjusts the threshold based on said optimal variation.
26. Method according to anyone of the preceding claims, wherein the method further comprises deploying the updated neural network into the computer vision unit.
27. Method according to claim 26, wherein the neural network is deployed into the computer vision unit when an improvement in the pose estimation is observed between the baseline neural network and the updated neural network.
28. Method for updating an autonomous charging device (ACD), the ACD comprising
- an end effector for supporting and moving a vehicle charging connector,
 - a camera
 - a motion control unit, and
 - a computer vision unit for socket-pose estimation,

wherein the computer vision comprises at least a baseline neural network, the motion control unit being configured to control the motion of the effector for plugging the connector into a vehicle socket using a pose estimation from the computer vision unit using an image of the socket recorded by the camera,
5 wherein the motion control unit comprises a baseline compensation function compensating for an inaccuracy between an actual pose and a target pose, wherein the target pose is a pose where the motion control unit controls the end effector to move towards, and wherein the actual pose is the end pose where the end effector is effectively
10 moved towards,

the method comprising:

- d) Receiving an updated neural network for the computer vision unit;
- e) Determining a variation in a pose-estimation inaccuracy between the baseline neural network and the updated neural network; and
- 15 f) Calibrating the motion control unit by updating the baseline compensation function based on the determined variation in pose-estimation inaccuracy.

29. An autonomous charging device comprising:

- an end effector for supporting and moving a vehicle charging connector;
- a camera;
- 20 – a motion control unit;
- a computer vision unit for pose estimation, comprising a baseline neural network; and
- wherein the motion control unit is configured to control the motion of the end effector for plugging the connector into a vehicle socket using a pose estimation
25 from the computer vision unit using an image of the socket recorded by the camera; wherein the motion control unit comprises a baseline compensation function compensating for an inaccuracy between an actual pose and a target pose; and
- a control device

30 characterized in that the control device is configured to:

- receive an updated neural network for the computer vision unit;
- determine a variation in a pose-estimation inaccuracy between the baseline neural network and the updated neural network; and
- calibrate the motion control unit by updating the baseline compensation
35 parameter based on the determined variation in pose-estimation inaccuracy.

30. The autonomous charging device according to claim 29, wherein the control device is further configured to:

- obtain a baseline inaccuracy between a target pose of the end effector and an actual pose of the end effector, and generating a baseline compensation function based on said baseline inaccuracy, wherein the target pose is determined using an output of the computer vision baseline neural network;
- adjust the motion control unit by setting a baseline compensation parameter using the baseline compensation function to compensate for the obtained inaccuracy.

10