Title:

Vision-based Control of Robotic Conductive Charging Systems for Electric Vehicles

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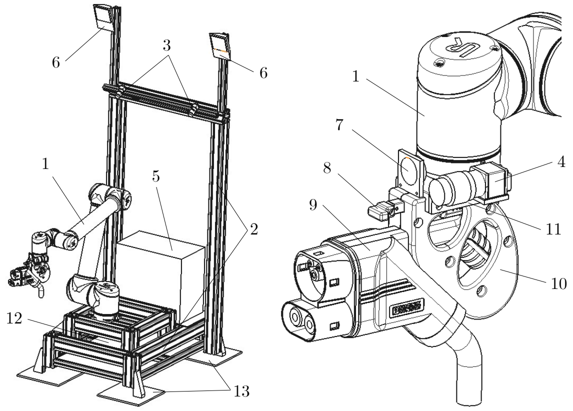
Introduction:

The increasing popularity of electric vehicles (EVs) and autonomous driving are calling for new solutions regarding battery charging. Automated charging with standard connector technologies has the potential for offering high charging power by minimal EV- and infrastructure attachments. Basically, standardized charging cables are not designed for an automated connection. One challenge for the control of robotic systems exists in the accurate and robust determination of the charging inlet position for sufficiently exact guiding the charging connector. The present work introduces an accurate, robust as well as cost-effective inlet position determination method based on 2D-cameras in combination with shape-based 3D-matching procedures. This includes the analyses of inlet position detection challenges and the definition of sensor requirements as well as the development of CAD shape-models and the conduction of experimental test series.

Robot-based Automated Charging of Electric Vehicles:

Automated charging with conductive standards (ACCS), e.g. the Combined Charging System (CCS) [1] or Charge de Move (ChaDeMo) [2], can provide both high customer comfort and safe operation. Standardized coupling systems are widely used and able to transfer very high charging power. Previous works presented automated conductive charging systems [3], [4] and [5]. However, no feasible solution for series application has been applied yet. One of the difficulties lie in the accurate and robust charging inlet position detection and the provision of data for an exact control of the connector coupling process under consideration of robustness and cost demands, [6].

Figure 1 shows CAD-models of an ACCS prototype that was developed at the Institute of Automotive Engineering at University of Technology in Graz in cooperation with project partners, [7]. The prototype enables cable connection and disconnection at various serious production EVs via standard charging connectors. Particularly important for the functionality are the newly developed sensor technology as well as CAD-shape models for vehicle classification and inlet position detection.



Position	Description
1	Robot manipulator
2	Charging station frame
3 & 4	2D-cameras
5	Robot control box
6 & 7	Light Emitting Diodes (LED)
8	Linear actuator
9	CCS Type 2 connector
10 & 11	Adapters
12	Arduino UNO Board
13	Rubber damper

Fig. 1: CAD-model of an ACCS charging station prototype and the prototype robot head tool including CCS Type-2 standard connector, [7].

Challenges and Requirements:

Figure 2, left, represents a charging lot and exemplary position frames of vehicle $\{V\}$, charging inlet $\{I\}$, parking lot $\{R\}$ and the ACCS base $\{A\}$. The variable EV parking position $\{V\}$ is characterized by translational and rotational position displacements in relation to $\{A\}$. An automated charging device has to compensate displacements by determining the inlet's 3D-position (figure 2, right, $\{I\}$) in its 6 degrees of freedoms. For an actual application of a standardized charging plug, the translational sensor requirements are less than 0.5 mm and the rotational demands are in a range of under 1.4 degrees, as experimental investigations showed. These high requirements on position detection and robotics system control represent a serious challenge for the development of an automated charging station under reasonable cost boundaries. The target of an interoperable ACCS handling applicable for different EV types increases the automation complexity, even more, [7].

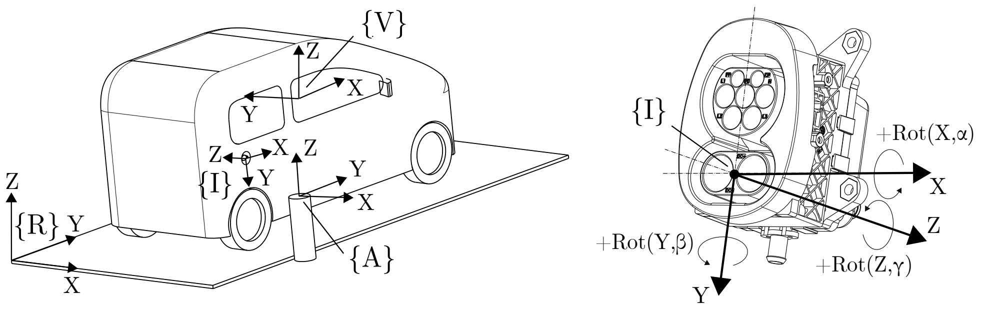


Fig. 2: Left: Exemplary representation of vehicle- and inlet positions on an ACCS charging lot. Right: CCS-Type 2 charging inlet 3D-position frame-model, [7].

Vehicle and Charging Inlet Recognition:

In the present approach, 2D-cameras are able to maintain the required ACCS prototype inlet- and vehicle detection accuracy, range and cost requirements and thus provide the basis for sensors selection, [10]. The object recognition process is separated into the tasks vehicle classification, rough- and accurate inlet position detection. Figure 3 shows the vehicle- and the inlet position recognition process. The process steps *Recognition I* and *Recognition II* are carried out by the same 2D-camera system and include *Vehicle recognition* as well as *Basic inlet position detection* and the *Charging start trigger*. An additional 2D-camera is responsible for the *Advanced inlet position detection* in the process step *Recognition III*. Both vehicle classification and inlet 3D-position detection, are conducted by 2D-camera images and shape-based 3D-matching, [7].

Shape-based 3D-matching uses contours, provided e.g. by a *Computer Aided Design* (CAD)-model of known objects, to estimate their position and orientation (pose) in a camera image, [8]. Range and field of view depend on the application and can be specified. In course of the specific development, virtual cameras are placed around the 3D-object model, and the 3D-contour is projected into the lens plane of each camera position. In this way, the 3D-shape model stores 2D-representations for each view. In the matching process, the 2D-shape representations are used to find the best matching view. During the process, the object pose result is improved step-by-step, [9].

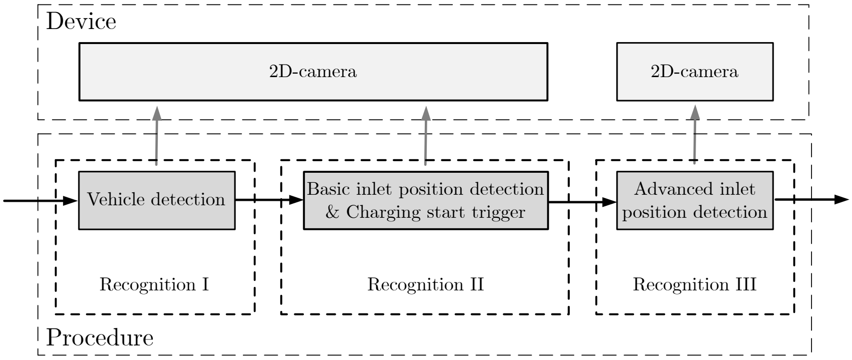


Fig. 3: ACCS object recognition process including procedures for vehicle and inlet 3D-position detection, [7].

CAD Shape-Models:

Vehicle-specific distinctive contours enable the identification and classification of the EV at the charging lot, [10] and [11]. Figure 4 shows different views of the CAD shape-model of a test vehicle's rear right wheel fender. This model can serve as a template for the shape-based 3D-matching process, which is based on a database of rear wheel fenders of typical EVs. In this way, a match provides information about vehicle type and vehicle position on the charging lot. Identification and classification is enabled without vehicle adaptations and additional communication, e.g. transmitter, RFID or sensor systems, [7].

Matching is based on contour detection (edges) in an image. The stronger contours appear and are pronounced in an image, the better they can be captured. Accurate and robust inlet position matching results require a suitable 3D-CAD model for the shape-based 3D-matching model generation. For matching of the charging socket, one challenge includes the development of a universal interoperable 3D-shape-model for standardized charging inlets. In case of the CCS Type-2 inlet, the standard [2] defines the geometrical shape of all parts (figure 4, right, position 1), involving DC connector (figure 4, right, position 2) and socket frame (figure 4, right, position 3) within the marked border (figure 4, right, position 4), which has been defined to be considerd in the machting model. With this approach, the inlet position detection works without additional supporting attachments, e.g. markers, and does not require a change of the standardized geometry.

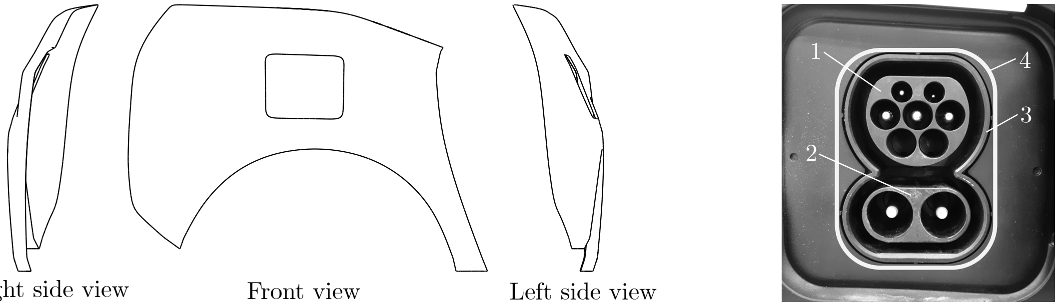


Fig. 4: Left: Different views of the 3D-CAD fender surface model. Right: Picture of a CCS Type-2 charging inlet, [7].

Application and Testing:

The system was tested and evaluated under different test scenarios. These include experiments with different vehicles under indoor and outdoor conditions. Figure 5, left, shows the 3D-CAD surface-model including the pre-defined reference coordinate system R_c. Position and orientation of the inlet in the captured camera image are related to R_c. An exemplary positive matching result and the corresponding inlet pose detection during tests are displayed in figure 5, right, M and $\{I_M\}$. For sensor technology evaluation, the detection time duration and the detection process, supported by Light Emitting Diodes (LED), at different parking positions and light conditions were recorded and evaluated during the test series, [7].

Further test series comprised the entire automated charging process, including driving in and parking the vehicle, recognition of vehicle and inlet by the vision system, plug-in and plug-out of the charging cable, leaving the charging station as well as practised and unpractised drivers who directed the test vehicles to the charging station and parked the car near the charging station.

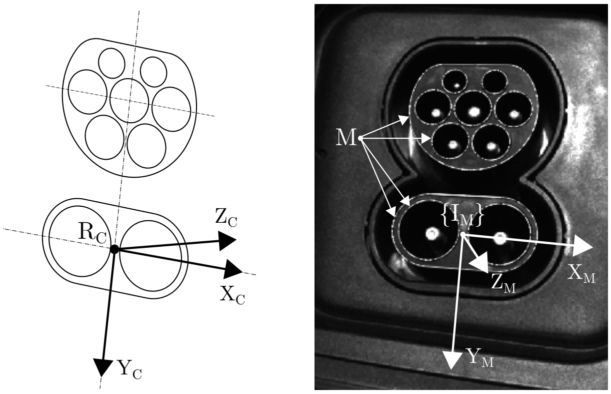


Fig. 5: Left: Charging inlet CAD-model as template for shape-based 3D-matching. Right: Matching result of an image from the robot-head 2D-camera, [7].

Conclusions:

The present work introduces a new approach for accurate and cost-efficient object detection for automated charging of electric vehicles with conductive standards (ACCS) by combination of CAD-based model provision and camera-based object recognition. The results support a further development of ACCS, which opens advantegous possibilities to guide robot-controlled systems for automated charging of different electric vehicle types with a high robustness of operation.

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