Robotic Plug-in Combined Charging System with Improved Robustness †

Josef Cernohorsky [1], Pavel Jandura [2,*]

[1] Technical University of Liberec; josef.cernohorsky@tul.cz

[2] Technical University of Liberec; pavel.jandura@tul.cz

* Correspondence: pavel.jandura@tul.cz; Tel.: +420-48-535-3861 (P.J.)

† Presented at the 6th International Electronic Conference on Sensors and Applications,
   15–30 November 2019; Available online: https://ecsa-6.sciforum.net/

Abstract: This paper describes the development of algorithm robotic plug-in of charging system for mobile platform. In the first chapter, there is a short overview of possibilities of automatic plug-in system, including proprietary industrial solution. In the main part, there is a description of system based on UR robot with build-in force torque sensors and Intel RealSense Camera. This camera combines IR depth lens with regular RGB camera and 6 DOF inertial sensor, which is used in our application too. The conventional solution of this problem is usually based on RGB image processing in various state of art, from simple pattern matching, neural network or genetic algorithm to complex AI solution. The quality of the solution mostly depends on robustness of image processing. In our cases, we use simple sensor fusion. Thanks to multiple information and constrain of values, we can assume, if algorithm is proceeding successfully or not. The system uses the internal parameters of the robotic arm, e.g., end-effector position and orientation and force-torque information in tool center point. The next information is RGB camera image and camera depth image, and the inertial unit build in camera. The other important information is the location of the vehicle inlet on the mobile platform, where the shape of mobile platform is considered as constrain for image processing. The system is validated only on physical model with CCS Type 2 plug and vehicle inlet, because the mobile platform is under construction by another team.

Keywords: image processing; sensor fusion; robotic system; pin-in-hole problem

1. Introduction

The autonomous mobile platforms will be more and more common for interoperation logistics [1,2]. The key feature how to reach high duty cycle of the battery powered platform is the use of the High Power Charging (HPC) system [3] or battery swapping station [4]. Most of the platforms use proprietary solution for charging [5], mostly because there is still not available a standardized Automatic Connection Device Underbody (ACDU) interface [6]. But thanks to the HPC systems, now widely expanding in public charging infrastructure for on-road vehicles, the use of standardized solution makes sense. The disadvantage of this standardized solution is that the used Combined Charging System (CCS) Type 2 [7] is not designed for autonomous robotic handling rather for human service.

2. Quick Overview of Possible Solution

We concerned ourselves only about robotic plug-in charging system, because battery swap needs an additional infrastructure and floor space.

The localization of the mobile platform can be handled by sensor fusion of several different sensor principles [8,9]. Typically, odometry, 9 DOF sensor, combines accelerometers, gyroscopes and magnetometers, GPS or Ultra-Wideband (UWB) absolute localization [10] and even advanced visual systems. This attitudes are not discussed in the paper. The typical outputs of this localization system are not precise enough to reach charging connector without additional localization system, or mechanical guidance.

3. Materials and Methods

For our experiment, we use dummy model of the CCS Type 2 plug and the vehicle inlet. The UR3 robot is suitable as a low power variant and an Intel Realsense D435i camera was used. Matlab was selected as the development environment. The camera was steady, not on robotic arm, but in the future it can be changed. The basic camera image is in the Figure 1.
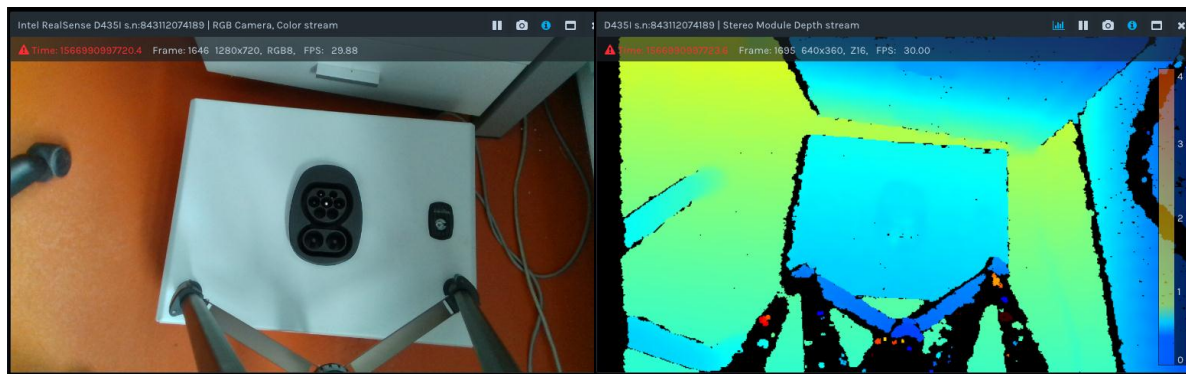

(**a**)   (**b**)

Figure 1. Basic (raw) capture from Intel RealSense D435i camera (**a**) Standard RGB picture; (**b**) Depth image (both pictures obtained by RealSense Viewer).

4. Results

The problem can be separated into two sections, the results of image processing, which provide position and orientation for second part, robotic control.

4.1. Image Processing

The data is provided through SDK by single array, so it must be restructuralized to (m-n-…) in Matlab to display the image. Thanks to a known camera distance from inlet, we can filter depth data to get the X-Y plane of the cabinet.
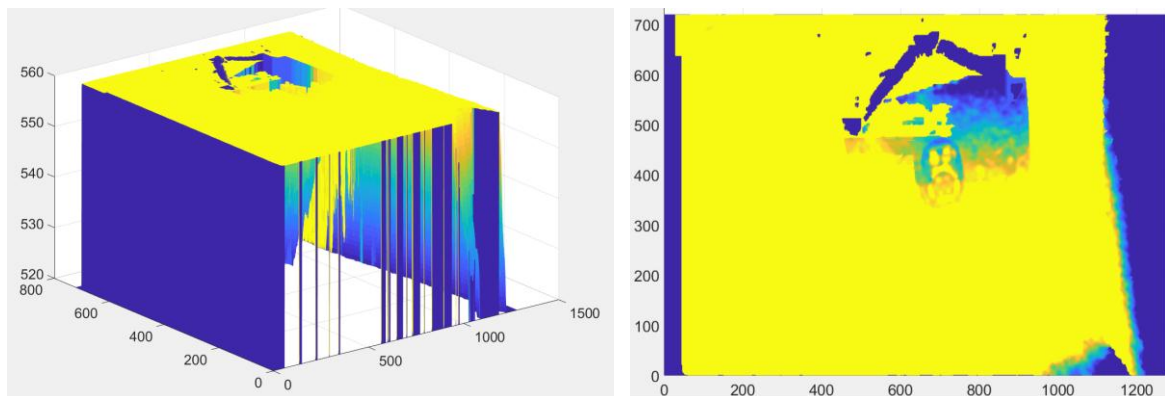

(**a**)   (**b**)

Figure 2. Depth data in the distance of 520-560mm from camera. (**a**) Shows nice "candidate valley" where the inlet should be found; (**b**) Shows data where the inlet is barely visible and includes the IR scanning relicts.

The inlet recognition is based on visible image pattern matching, depth camera information verification that improves robustness of the solution. The main point is in visible image processing, where thanks to elliptical shape of the CCS inlet we find the area with proper contour and size, results are displayed in the Figure 3.

(**a**)   (**b**)
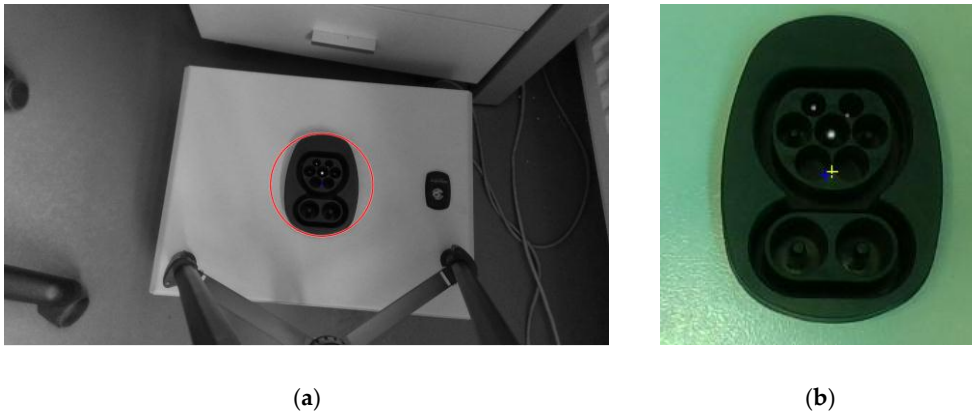
Figure 3. Visible image processing: (**a**) basic circular detection of the inlet; (**b**) two center points based on elliptical detection (yellow is more accurate).

The center point is reliably detected; the blue one was based on different algorithm, where the shadow slightly influences the position. From optical image we therefore get center point and orientation of the object.

The next level of image processing is pattern matching, where preimage is labeled and then found in picture, Figure 4. We have to say, that this algorithm really depends on sensitivity setting for labeling. This algorithm is iterative, when the center point is detected out of the depth region, the results are wrong and the sensitivity is adjusted and algorithm is started again, 5 times max.

(**a**)   (**b**)
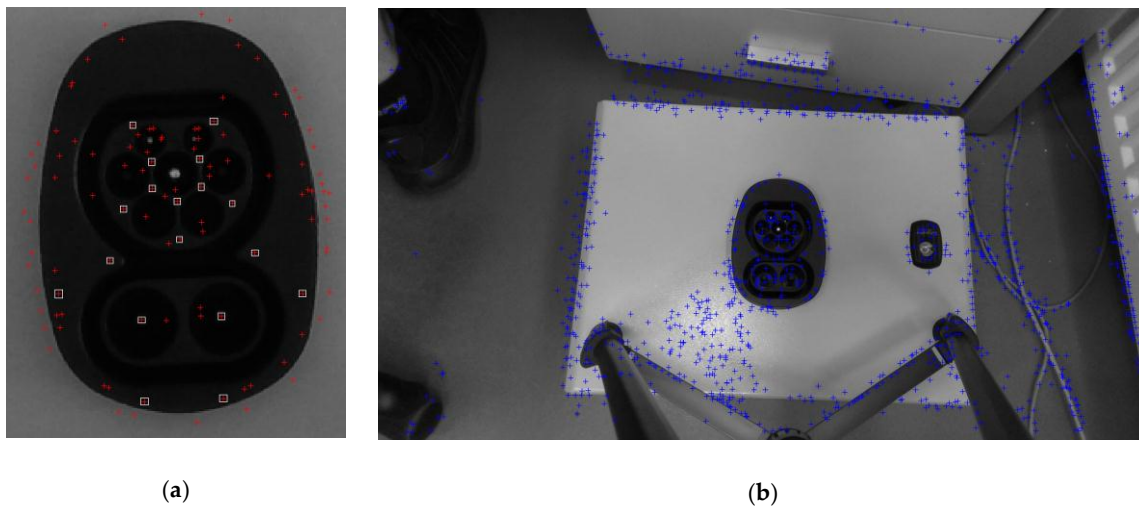
Figure 4. Featured extraction on "plain black" (**a**) White markers highlight the significant natural points, centroids of surfaces, close section on pinholes etc. ; (**b**) glitter on cabinet plane and inlet with markers to pattern match.

4.2. Robotic Control

The robotic control is based on TCP/IP communication, where the tool of CCS Type 2 plug is set up on the robot. Input data are the center point and Z-tool rotation orientation, the output data are 6 DOF force and torques measured by robot. Before first use, a simple camera calibration must be done, where the pairs of camera point and robotic coordinates are matched together by affine transformation. The plugging process is separated to several steps.

- "Reaching the first contact" (orientation of tool Z-tool axis rotation is not compensated). The position setpoint is above the plane and robot moves to Z-tool axis Force threshold.
- "Force controlled motion" (adjustment of position X-Y plane, to minimize tangential forces).
- "Partial plug-in" (Z-tool rotation from positive torque threshold to negative torque threshold and setting the orientation to half between those limits.)
- "Finalization of plug-in" to reach the proper depth from initial contact to ensure the full plugging–in. This operation must be made within force torque limits, to ensure proper orientation in X,Y axis.

Those steps are nowadays realized in Matlab, thanks to faster software development, but for final stage they will be implemented into the robotic controller for simplification of control process.

5. Discussion

The image processing uses several approaches how to detect the CCS Type 2 vehicle inlet. The depth information is used like "candidate valley" for verification. For final realization, it seems the "eye on hand" arrangement is better. The mandatory enhancement must be made for lighting, since daylight and fluorescent ambient lighting (for worst case study of the algorithm) were used for our experiment. The improvement in lighting helps to feature extraction on inlet and can significantly improve the pattern matching.

The last problem is in force torque control during plug-in operation, where the end effector force torques are reconstructed from joints values, independent force torque sensor could help and such solution will be used in further research. The iterative attitude via several tool axis is time consuming, in future we would like to develop algorithm to measure the forces and torques and calculate the compensative motion in one-step for all axis.

The important fact is that the recognition algorithm is reliable, there are almost no positive false, the inlet is recognized, but not present. The negative false are typical in case, when part of the inlet is out of range or during bad lighting conditions. This must be improved during next phase of research by better lighting and camera on robotic hand arrangement. However, the Matlab with image processing and robotic toolboxes is good environment for development.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. Bacik, J.; Durovsky, F.; Biros, M.; Kyslan, K.; Perdukova, D.; Padmanaban, S. Pathfinder–Development of Automated Guided Vehicle for Hospital Logistics. *IEEE Access* **2017**, *5*, 26892–26900, doi:10.1109/ACCESS.2017.2767899.
2. Hossain, S.; Ali, M.; Jamil, H.; Haq, M. Automated guided vehicles for industrial logistics—Development of intelligent prototypes using appropriate technology. *The 2nd International Conference on Computer and Automation Engineering (ICCAE)* **2010**, doi:10.1109/ICCAE.2010.5451466.

3. Phoenix Contact: High Power Charging—CCS-based fast charging with up to 500 A, 2019. Available online: https://www.phoenixcontact.com/assets/downloads_ed/global/web_dwl_promotion/52007586_EN_HQ_E-Mobility_LoRes.pdf (accessed on 21 October 2019).

4. Mak, H.; Rong, Y.; Shen, Z. Infrastructure Planning for Electric Vehicles with Battery Swapping. *Management Science* **2013**, *59*, 1557–1575, doi:10.1287/mnsc.1120.1672.

5. Staubli: Automatic Rapid Charging Solution QCC for AGV, 2019. Available online: http://ec.staubli.com/AcroFiles/Catalogues/SZ_APP-RapidCharge-AGV-11014168_(en)_hi.pdf (accessed on 21 October 2019).

6. Charinev.org, 2019. Available online: https://www.charinev.org/acd/?no_cache=1 (accessed on 21 October 2019).

7. CharIN: Combined Charging System Specification, 2019. Available online: https://www.charinev.org/ccs-at-a-glance/ccs-specification/ (accessed on 21 October 2019).

8. Fauser, T.; Bruder, S.; El-Osery, A. A comparison of inertial-based navigation algorithms for a low-cost indoor mobile robot. *12th International Conference on Computer Science and Education (ICCSE)*. Houston, TX, **2017**, 101–106, doi:10.1109/ICCSE.2017.8085471.

9. Cernohorsky, J.; Jandura, P.; Mach, O. Mobile robot localization and object description. *18th International Carpathian Control Conference (ICCC)*. Romania, **2017**, 503–506, doi:10.1109/CarpathianCC.2017.7970452.

10. Wang, J.; Gao, Y.; Li, Z.; Meng, X.; Hancock, C.M. A Tightly-Coupled GPS/INS/UWB Cooperative Positioning Sensors System Supported by V2I Communication. *Sensors* **2016**, *16*, 944.