Development of Control Interface for a Desktop–Sized Articulated Robot

– Proposal of Hyper CLS data and Implementation of Basic Functions –

Kohei Miki[1], Fusaomi Nagata[1], Kei Furuta[2], Koki Arima[1], Tatuki Shimizu[1], Takeshi Ikeda[1], Hirohisa Kato[2], Keigo Watanabe[3], Maki K. Habib[4],
[1]Graduate School of Engineering, Sanyo-Onoda City University
[2]Department of Mechanical Engineering, Sanyo-Onoda City University
1-1-1 Daigaku-Dori, Sanyo-Onoda 756-0884, Japan
(Tel: +81-836-88-4547; E-mail: nagata@rs.socu.ac.jp)
[3]Graduate School of Natural Science and Technology, Okayama University,
3-1-1 Tsushima-Naka, Kita-ku, Okayama 700-8530, Japan
(Tel: +81-86-251-8064; E-mail: watanabe@sys.okayama-u.ac.jp)
[4]Mechanical Engineering Department, School of Sciences and Engineering,
The American University in Cairo,
AUC Avenue, P.O.Box 74, New Cairo 11835, Egypt
(Tel: +20-2-2615-3083; E-mail: maki@aucegypt.edu)

Abstract

In designing and manufacturing process using CAD/CAM systems, cutter location source (CLS) data is generally used for intermediate data to finally generate numerical control (NC) data for various types of NC machine tools. In common CLS data, GOTO statements are mainly included to designate the position and orientation of a cutting tool. However, it is not supported by such standardized CLS data for industrial robots and mechatronics systems to have special or customized statements for handling an end-effector and a camera system, functioning visual feedback controllers and AI systems like convolutional neural networks (CNNs).

In this paper, hyper cutter location source (HCLS) data and its control interface are introduced for a desktop-sized articulated robot to cope with such extended functions as required for automations in industrial production lines. HCLS data can include extended numerical commands, e.g., for gripper control, selection of joint or linear interpolation, camera snapshot control, for estimation of object's orientation using AI, and visual feedback control to approach to a target object for picking. The effectiveness of the proposed method is demonstrated through pick and place experiments using a small 4-DOFs articulated robot named DOBOT Magician.

1 Introduction

Articulated and SCARA-types of industrial robots have been introduced in the production lines of many industrial products. Recently, for example, the system presented by Piotr and Krzysztof could physically simulate the production process automation of gears using multiple robots [1]. Avanzato developed a laboratory exercises using the MATLAB Robotics Systems Toolbox and a ROS-enabled robot arm named DOBOT Magician as part of his university lectures [2]. When robots are used in manufacturing, teaching data is generally created by off-line robot programming using a teaching pendant. Off-line control using the program is also possible, but it requires the use of a language specific to the robot manufacturer, and leads to the lack of versatility.

To cope with those problems, some attempts have been devoted to integrate robot applications with CAD/CAM systems used in the design and manufacturing process. For example, Johannes and Sigrid developed the KUKA Robot Language plug-in for Rhinoceros, which was affinity with a commercial 3D CAD software for the manufacturing industry [3]. Nagata et al. proposed a system to control robots according to cutter location source (CLS) data, which was a tool path that could be standardly generated by general CAD/CAM systems without using any robot language [4]. Pedro and Nuno proposed an application that allowed off-line programming of robots from CAD drawings running on a common 3D CAD package [5]. For the robot grinding system, Shenshun et al. developed a system that converted the CNC G-Code program created in NG NX3 into a Motoman program for the Yaskawa robot [6]. As can be seen, robot interface with CAD systems has been provided to a certain extent, however, it seems that the integration with an AI system and a visual feedback (VF) controller has not been well established yet.

Figure 1 shows the DOBOT Magician which is a desktop-sized articulated robot used in this work [7]. Table 1 shows the specifications of the robot. It only

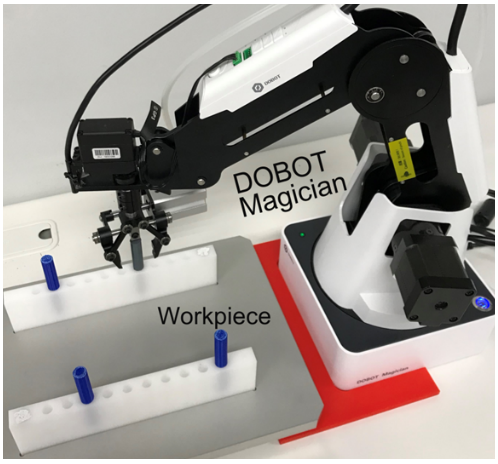

Figure 1: Desktop-sized 4-DOFs articulated robot named DOBOT Magician [7].

Table 1: Technical parameters of DOBOT Magician.

Type	4 DOFs(X,Y,Z,R)
Maximum payload	500 g
Maximum reach	320 mm
Motion range of Base	$-90° \sim 90°$
Rear Arm	$0° \sim 85°$
Forearm	$-10° \sim 90°$
End-effector rotation	$-135° \sim 135°$
Maximum rotation speed	320°/s
Repetitive position accuracy	0.2 mm

has 4-DOFs less than 6-DOFs generally used in industrial robots, however, it is characterized by its user-friendly teaching interface and rich API functions including kinematics and servo control that enable engineers to develop new customized applications. The authors have applied convolutional neural network (CNN) and visual feedback control to the development of a robot system based on DOBOT to perform a pick and place task considering the pose of target articles [9]. This system allows the robot to visually recognize workpieces on the table and pick them. However, there is a serious problem that command sequence written in MATLAB programming language have to be rewritten according to modifications or changes of desired tasks. To cope with this problem, the authors propose hyper cutter location source (HCLS) data which can describe not only essential functions such as MOVJ and MOVL included in original teaching data but also newly defined advanced commands such as VF_CONTROL for VF control and SNAPSHOT for camera control and so on. It is expected that the HCLS data can enhance the functionality and usability of conventional teaching and playback type industrial robots. The effectiveness is shown through experiments.

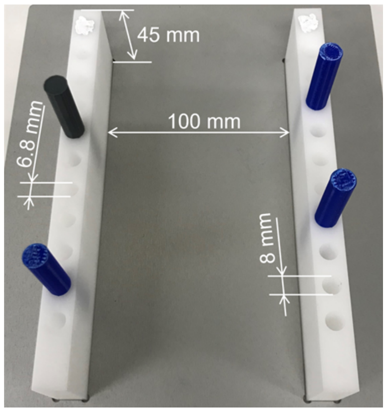

Figure 2: Jig and workpieces used in the pick and place experiment.

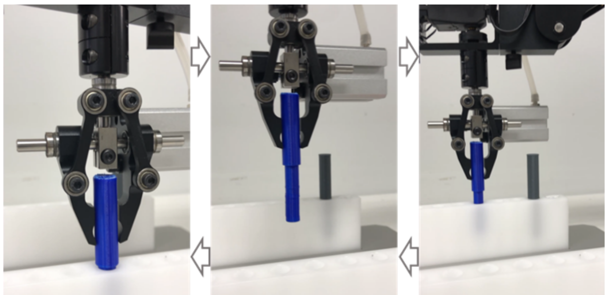

Figure 3: Repetitive and continuous pick and place experiment for a few hours.

2 Preliminary Experiment of Pick And Place Task with Small Clearance

In this section, a pick and place task with a small clearance is conducted as a preliminary experiment to evaluate the basic performance of the robot. A variety of small-sized industrial robots are provided from major industrial robot manufacturers. However, those robots are very expensive, so that it is not easy for small and medium-sized manufactures to purchase multiple units. In this study, first of all, basic pick and place performance of the tabletop 4-DOFs robot as shown in Fig. 1 is evaluated through experiments conducted by nine students in our laboratory. Through the experiments, actual vibration problems caused by the low rigidity frequently made us suffer. This is especially true when the gripper attached to the arm tip is fully extended in either the left, right or front direction while grasping a workpiece.

Against such a background, an experiment is conducted to evaluate the actual performance of the robot through a pick and place operation with a condition of a small clearance 0.7 mm. Figure 2 shows an example consisting of plastic jigs and cylindrical resin molded articles. The jig has 10 holes with a diameter of 8 mm aligned at intervals of 7 mm. The diameter of the articles is 7.3 mm.

As for teaching process, nine students individually conducted teaching tasks using the same types of nine

```
<root><DobotType><item_0>Magician</item_0></DobotType><row_Studic
/><item_2>274.66730000000001</item_2><item_3>-115.2764</item_3><
22.3676</item_5><item_10>0.0</item_10><item_11>0</item_11></row0>
115.2764</item_3><item_4>61.01800000000001</item_4><item_5>-22.
/><item_2>274.66730000000001</item_2><item_3>-115.2764</item_3><
22.3676</item_5><item_10>0.0</item_10><item_11>0</item_11></row2>
```


Figure 4: Example of text codes included in a playback file generated using DobotStudio provided by the robot maker.

```
Absolute for Magician
GOTO/200,0,85,0,0.0,0,1
GOTO/198.118,-58.032,85,0,1,1,1
GOTO/198.118,-58.032,50,0,0.0,0,1
GOTO/198.118,-58.032,50,0,1.0,2,1
            ⋮
GOTO/198.118,-58.032,50,0,0.0,0,1
GOTO/198.118,-58.032,85,0,1.0,2,1
GOTO/200,0,85,0,0.0,0,1
```

Figure 5: Example of HCLS data converted from the playback file shown in Fig. 4.

robots, so that different nine teaching files were generated. In the teaching process, not only teaching points were finely positioned, bat also pause time of the gripper open/close was adjusted. The teaching tasks were carried out using DobotStudio-V1.9.4 provided by Shenzhen Yuejiang Technology. Figure 3 shows an example within the pick and place experiments conducted by nine students.

It was observed from the experiments that the nine robots could successfully continue each pick and place task stably for several hours. In particular, smooth insertion of the molded products into the holes was achieved by selecting MOVL for a straight line movement, instead of MOVJ whose trajectory is deviate from a straight line. Thus, it was confirmed that even the low-cost and low-rigidity tabletop robot can be applied to such a pick and place task as introduced in this section.

3 Proposal of Hyper Cutter Location Source (HCLS) Data

In this section, the concept of HCLS data and its interface with the robot are described. HCLS data enables to let the robot possess and execute promising extended functions such as VF controller, CNN for defect detection and orientation estimation, and so on.

3.1 About HCLS data

In the previous section, a simple pick and place task using a robot is shown using the provided teaching software named DobotStudio which can generate the playback file as shown in Fig. 4. The playback file consists of text codes and can be edited with a text editor such as Notepad. However, the structure of the file includes no line feed codes, so that it is difficult for users to rapidly understand the contents and meaning. Moreover, at the present stage, DobotStudio has not yet supported users' needs for new advanced functions such as the implementation of visual feedback controller, AI such as CNN, SVM and so on.

Table 2: Extended statements available in HCLS data.

SNAPSHOT	Snapshot with a camera
ORIENTATION	Estimation using regionprops
CNN_ORIENTATION	Estimation using CNN
VF_CONTROL	Visual feedback control
CNN_DEFECT	Defect detection using CNN
MOVZ z	Z-directional motion to z.
OFFSET x, y, z	Camera offset x,y,z
GRIPPER_DISABLE	Gripper disable
GRIPPER_OPEN	Gripper open
GRIPPER_CLOSE	Gripper close
PAUSE t	Wait time for t [sec]

In this study, the authors propose HCLS data as shown in Fig. 5 that can deal with extended and advanced functions as shown in Table 2, e.g., shutter timing of camera, visual feedback control, single axis motion such as Z-axis and R-axis, use of various kinds of CNNs, and so on. Conventional standardized CLS data is generated by the main processor of an ordinary CAD/CAM system such as Creo, in which two main statements such as GOTO for linear interpolation and CIRCLE for circular interpolation are sequentially described according to a tool path for an NC machine tool. On the other hand, in the proposed HCLS data, a GOTO statement can further include additional numerical information, i.e., pause time, gripper open(1) or close(2) and motion mode of either MOVJ(1) or MOVL(2). For example, in the case of DOBOT Magician, a GOTO statement is written as

$$\mathrm{GOTO}/x, y, z, r, 0.5, 1, 2$$

where (x, y, z) is the position in robot absolute coordinate system; r is the rotation angle of R axis; 0.5 means pause time; subsequent 1 and 2 act gripper open and motion mode of MOVL, respectively.

In addition, it can include other several advanced statements as shown in the Table 2. For example, ORIENTATION conducts a calculation of object's orientation using a API function named 'regionprops( )'; CNN_ORIENTATION estimates object's orientation using a CNN trained in advance; VF_CONTROL activates our implemented visual feedback controller to track an object; CNN_DEFECT detects defects included in a snapshot image.

3.2 Playback experiment using HCLS data

Figure 6 shows the control interface, i.e., operation dialogue, based on HCLS data for operating the small

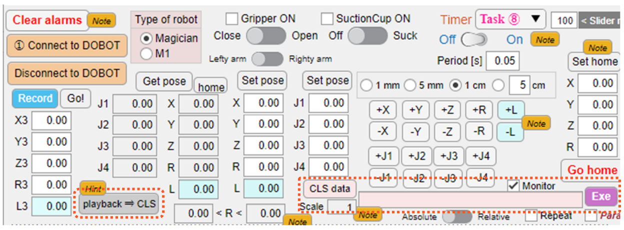

Figure 6: Developed robot operation dialog, through which HCLS data can be generated, selected and executed.

tabletop robot. The control interface was developed on MATLAB, in which the API functions provided by this robot manufacturer were used for servo control and kinematics-related calculation considering the length of tool offset.

After the playback format data generated in the experiment described in section 2 was converted to HCLS data using the dialogue, the same robotic pick and place task could be successfully performed using the HCLS data. Therefore, it could be confirmed that the HCLS data and the developed control interface have equivalent performance compared to the provided robotic user interface DobotStudio in terms of stability and response.

4 Experiments on HCLS Data with Advanced Statements

Table 2 includes advanced statements available in HCLS data. In this section, a pick and place experiment using VF_CONTROL, OFFSET and CNN_ORIENTATION is demonstrated. They are the statements for our developed VF controller, tool offset compensator between a gripper and an endoscope camera as shown in Fig. 7, and orientation estimator by CNN.

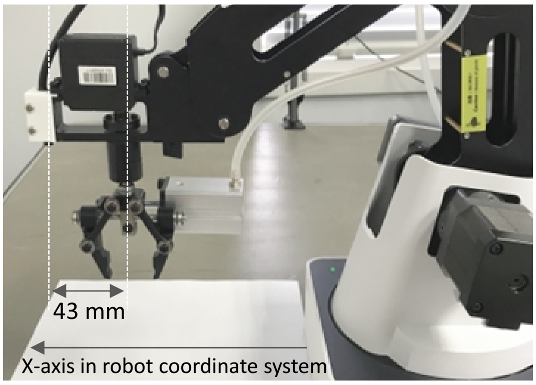

Figure 7: Camera offset (43,0,0) between the endoscope camera and the gripper.

4.1 Visual feedback controller

The VF control is performed using the small endoscope camera with a resolution of 640×480 optionally equipped close to the gripper. Figure 8 illustrates an overview of the VF control. In this control, the goal is to control the position of the end-effector so that the error between the COG of an object in the image coordinate system and the center position of the image can become zero. Firstly, in the case of a binary image where the background pixel value is 0 and the object pixel value is 1, the position of the COG calculated by the following equations.

$$I_x = \frac{\sum_{x=1}^{640}\sum_{y=1}^{480} xP(x,y)}{\sum_{x=1}^{640}\sum_{y=1}^{480} P(x,y)} \tag{1}$$

$$I_y = \frac{\sum_{x=1}^{640}\sum_{y=1}^{480} yP(x,y)}{\sum_{x=1}^{640}\sum_{y=1}^{480} P(x,y)} \tag{2}$$

where (x, y) is the position of a pixel in the image coordinate system; $P(x, y)$ is the pixel value at that position. Secondly, the error $\boldsymbol{e}(k)$ between the COG ($\boldsymbol{I} = [I_x\ I_y]^T$) and the center of figure ($\boldsymbol{x}_d = \left[\frac{640}{2}\ \frac{480}{2}\right]^T$) in the camera coordinate system is given by

$$\boldsymbol{e}(k) = \boldsymbol{x}_d - \boldsymbol{I}(k) \tag{3}$$

where k is the discrete time. Note that relation between the camera coordinate system and the robot coordinate system is illustrated in Fig. 9. Considering the relation, a PI control law $\boldsymbol{v} = [v_x\ v_y]^T$ is finally given by

$$v_x = -K_p e_y(k) - K_i \sum_{n=1}^{k} e_y(n) \tag{4}$$

$$v_y = -K_p e_x(k) - K_i \sum_{n=1}^{k} e_x(n) \tag{5}$$

where K_p and K_i are the gains of P-control and I-control, respectively. Eqs. (4) and (5) control the gripper so that $\boldsymbol{X}_d$ and $\boldsymbol{I}(k)$ can be overlapped without calibrating the two coordinate systems.

4.2 Experiments

An experiment using HCLS data including the advanced statements such as VF_CONTROL and CNN_ORIENTATION is conducted to demonstrate the effectiveness and validity. The detail of the HCLS data is shown in Fig. 10. Main control procedure is as follows: (1) gripper moves to an initial position, (2) endoscope camera approaches to the position just above an object by VF_CONTROL, (3) orientation of the object is estimated by CNN_ORIENTATION, (4) the R axis of the robot is rotated according to the estimated orientation, (5) gripper moves to the the position just above the object by OFFSET with (x, y), (6) the gripper opens, (7) the gripper goes down to

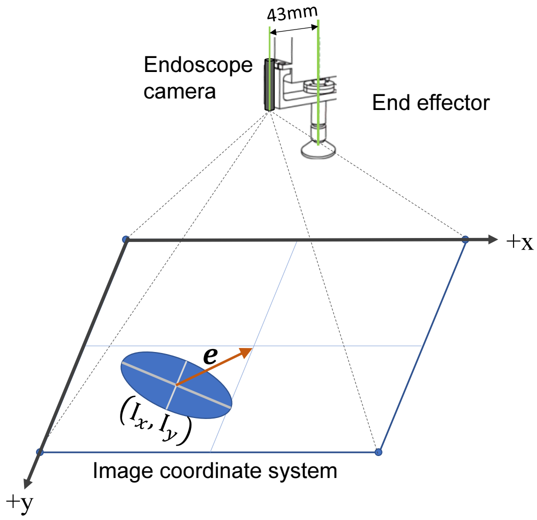

Figure 8: Position error in the image coordinate system during VF control mode.

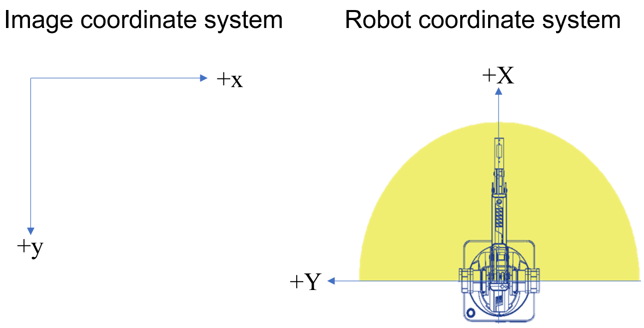

Figure 9: Relation between camera coordinate system and robot coordinate system.

$z = -33.0$, (8) the gripper closes to pick the object, (9) finally, the object is placed at a desired position.

Note that the CNN used in this experiment was built through transfer learning of GoogLeNet [9], also, the position compensated values (x, y) are obtained with the camera offset distance Δd between the the endoscope and the gripper as

$$x = \Delta d \cos(J_1) \tag{6}$$
$$y = \Delta d \sin(J_1) \tag{7}$$

where 43 mm is set to Δd in this experiment; $J1$ is the angle of joint 1. Figure 11 shows the experimental scenes using the HCLS data. Two different rectangular workpieces were successfully picked and moved to the desired position while grasping the exact center of the major axis. The VF control gains K_p and K_I were set to 0.1 and 0.01, respectively.

5 Conclusion

To evaluate the basic teaching and playback function of the tabletop robot, we first conducted a pick and place experiments of resin molded articles with a

```
Absolute for Magician
GOTO/200,0,55,0.0,0.0,0,1
VF_CONTROL
ORIENTATION
OFFSET
GRIPPER_OPEN
PAUSE 0.5
MOVZ -33.0
GRIPPER_CLOSE
PAUSE 0.5
MOVZ 55.0
GOTO/168.116,-160.408,55,-0.296,0.0,0,1
GOTO/168.116,-160.408,-33,-0.296,0.0,0,1
GRIPPER_OPEN
PAUSE 0.5
⋮
GOTO/200.0,0.0,55.0,0.0,0.0,0,1
```

Figure 10: HCLS data including advanced statements such as VF_CONTROL and CNN_ORIENTATION.

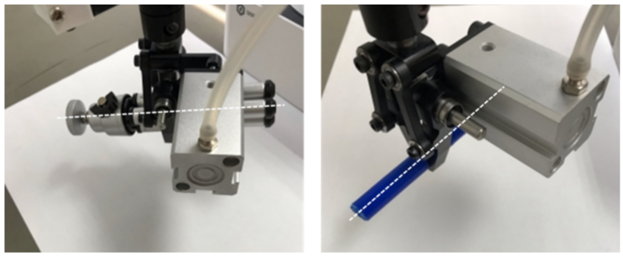

Figure 11: Experimental scenes using HCLS data including two advanced statements VF_CONTROL and CNN_ORIENTATION .

clearance of only about 0.7 mm by using the user interface provided the robot maker, so that the robot could stably continue the work for several hours. Next, we evaluated the basic functions of the proposed control interface for the robot being developed on MATLAB. After generating HCLS data from the taught data (i.e., playback file), the robot could similarly achieve long hours of playback motion using the HCLS data. The superiority of the proposed control interface based on HCLS data is its extensibility, i.e., various kinds of advanced statements for such as visual feedback control, camera control, CNN and so on.

In future work, we plan to apply the small-sized robots and the proposed control interface based on HCLS data to automation of other pick and place tasks moreover requiring defect detection and resultant classification, which even now are relying on human labor.

References

[1] Jaskolski P, Nadolny K (2019), Characteristics of functional subsystems of modular didactic production system for gear trains, Journal of Mechanical and Energy Engineering 3(4): 301–308

[2] Avanzato RL (2020), Development of a MATLAB/ROS interface to a low-cost robot Arm, In: Proceedings of 2020 ASEE Virtual Annual Conference Content Access: 14 pages

[3] Johannes B, Sigrid BC (2011), Parametric robot control: Integrated CAD/CAM for architectural design, In: Proceedings of the 31st Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA), pp. 242–251

[4] Nagata F, Okada Y, Kusano T, Watanabe K, (2017), Reverse and forward post processors for a robot machining system, In: Proceedings of 10th International Conference on Intelligent Robotics and Applications (ICIRA), pp. 70–78

[5] Pedro N, Nuno M, (2013), Direct off-line robot programming via a common CAD package, Journal of Robotics and Autonomous Systems 61(8): 896–910

[6] Shenshun Y, Shi J, Ming J (2010), Path generation and posture angle control of tool for robotic polishing system, Journal of Advanced Materials Research 102–104: 568–572

[7] DOBOT,https://www.dobot.cc/dobot-magician/product-overview.html

[8] Dobot Magician User Guide (2018): (https://www.dobot.cc/downloadcenter)

[9] Miki K, Nagata F, Ikeda T, Watanabe K, Habib MK (2021), Molded article picking robot using image processing technique and pixel-based visual feedback control, Journal of Artificial Life and Robotics 26: 390–395.