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CAD/CAM Interfaces for Articulated-Type Robots

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Abstract

In this study, CAD/CAM interfaces are proposed for articulated-type robots. They are an educational robot called DOBOT and an industrial robot called VS068. Two types of robot operating environments that can be used without conventional teaching process are presented. In the case of the DOBOT, paths called CLS (Cutter Location Source) data are interpretively converted into robot language codes line by line and are given to the robot controller through its API functions. Also, in the case of the VS068, position and orientation vectors calculated from the CLS data are given to the robot controller every sampling time through API functions provided by ORiN middleware. Due to the proposed systems, attractive outline fonts can be easily drawn and engraved without teaching tasks. The usefulness and validity of the proposed systems are evaluated through design, drawing and engraving experiments.

1 Introduction

Figure 1 shows the roles of the spline interpolation function of CLS data and the CAD/CAM interfaces for handling outline fonts proposed in this study. Already developed post processor can output the robot language for FANUC industrial robots from a tool path generated from CAM [1, 2]. In the Interpreter-like controller, we consider the function to execute CLS data line by line for an articulated robot DOBOT and its API while interpreting them into commands described in the robot languages [3]. Conventionally, a teaching playback method is generally used in order to operate robots. It consists of two modes. In teaching mode, a large number of desired positions and orientations are needed to be inputted using a teaching pendant. In playback mode, the robot is controlled repeatedly and accurately according to the taught data. To reduce the load of teaching process, we propose a CAD/CAM interface which enables the industrial robot VS068 to be directly controlled along CLS data. The CAD/CAM interface generates fine position and orientation quantity for the servo system and then sends them every sampling time to the servo

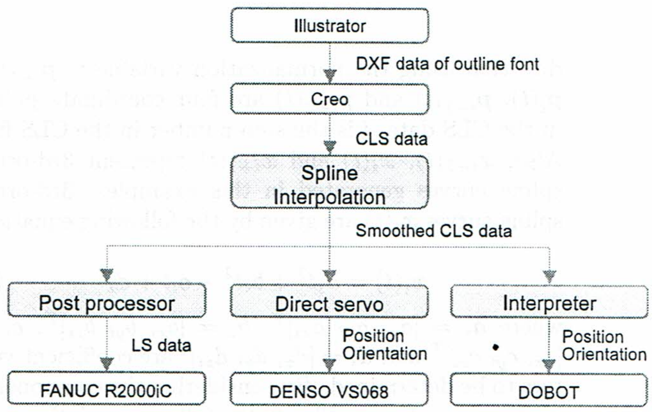

Figure 1: Role of the proposed post processor, direct servo, interpreter-like controller and spline interpolation to handle outline fonts.

system via API provided by ORiN middleware. As a result, complete teaching less operation is realized for the VS068 [4].

2 CLS Data Interpolation Method Along Spline Curves

Illustrator is a vector image editing software that can use various fonts and can convert created data to DXF data. High-end CAD/CAM software like "Creo" can import the DXF data and generate the corresponding CLS data. When a curved line is included in an original outline font, the main processor of CAD/CAM generally constructs CLS data with a large number of minute straight lines by linear approximation. For this reason, an interpolation of CLS data is effective for smoothing a linearly approximated trajectory. Many efforts have been already dedicated to the generation of smooth tool paths for industrial robots and numerically controlled machine tools [5, 6, 7, 8, 9, 10]. In this study, first of all, an interpolation method based on 3rd-order spline curves or 5th-order spline curves is reviewed to easily smooth original CLS data from ease of implementation [1, 3]. Figure 2 shows an example of spline curves in the x

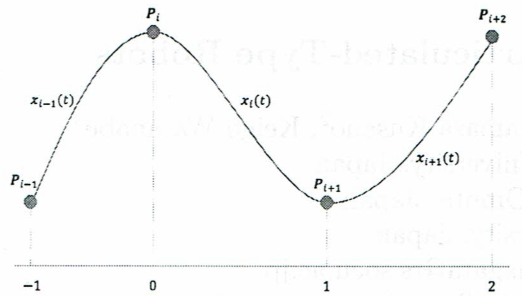

Figure 2: Third order spline curves for CLS data interpolation.

direction using the normalization variable t. $\boldsymbol{p}_{i-1}(t)$, $\boldsymbol{p}_i(t)$, $\boldsymbol{p}_{i+1}(t)$ and $\boldsymbol{p}_{i+2}(t)$ are four coordinate points in the CLS data, i is the step number in the CLS file. Also, $\boldsymbol{x}_{i-1}(t)$, $\boldsymbol{x}_i(t)$ and $\boldsymbol{x}_{i+1}(t)$ represent 3rd-order spline curves generated in this example. 3rd-order spline curves $\boldsymbol{x}_i(t)$ are given by the following equation.

$$\boldsymbol{x}_i(t) = \boldsymbol{a}_i t^3 + \boldsymbol{b}_i t^2 + \boldsymbol{c}_i t + \boldsymbol{d}_i \qquad (1)$$

where $\boldsymbol{a}_i = [a_{xi}\ a_{yi}\ a_{zi}]^T$, $\boldsymbol{b}_i = [b_{xi}\ b_{yi}\ b_{zi}]^T$, $\boldsymbol{c}_i = [c_{xi}\ c_{yi}\ c_{zi}]^T$ and $\boldsymbol{d}_i = [d_{xi}\ d_{yi}\ d_{zi}]^T$ are coefficient vectors to be determined. By considering the components in the x direction in Fig. 2, the following relations are obtained.

$$x_i(-1) = p_{x(i-1)} = -a_{xi} + b_{xi} - c_{xi} + d_{xi} \qquad (2)$$

$$x_i(0) = p_{xi} = d_{xi} \qquad (3)$$

$$x_i(1) = p_{x(i+1)} = a_{xi} + b_{xi} + c_{xi} + d_{xi} \qquad (4)$$

$$x_i(2) = p_{x(i+2)} = 8a_{xi} + 4b_{xi} + 2c_{xi} + d_{xi} \qquad (5)$$

Eqs. (2), (4) and (5) are rewritten by the following equation.

$$\begin{pmatrix} a_{xi} \\ b_{xi} \\ c_{xi} \end{pmatrix} = \begin{pmatrix} -\frac{1}{6} & -\frac{1}{2} & \frac{1}{6} \\ \frac{1}{2} & \frac{1}{2} & 0 \\ -\frac{1}{3} & 1 & -\frac{1}{6} \end{pmatrix} \begin{pmatrix} p_{x(i-1)} - p_{xi} \\ p_{x(i+1)} - p_{xi} \\ p_{x(i+2)} - p_{xi} \end{pmatrix} \qquad (6)$$

Since coefficient vectors in the y and z directions can be calculated in the same way, the segment between $\boldsymbol{p}_i$ and $\boldsymbol{p}_{i+1}$ are arbitrarily interpolated with $\boldsymbol{x}_i(t)$ $(0 \leqq t \leqq 1)$. By applying this process to all the points in the CLS data, spline curves for interpolating the CLS data can be generated. Further, setting the conditions given by Eqs. (7) and (8) allows to pinpointedly execute spline interpolation, so that important edge portions can be left.

$$\theta_k > \theta_{\min}\ (k = i, i+1) \qquad (7)$$

$$\|\boldsymbol{P}_{k-1}\boldsymbol{P}_k\| < d_{\max}\ (k = i, i+1, i+2) \qquad (8)$$

Eq. (7) means that the angle θ_k formed by adjacent two segments is larger than the minimum angle $\theta_{\min}$ set in advance. Also, Eq. (8) is a condition that the

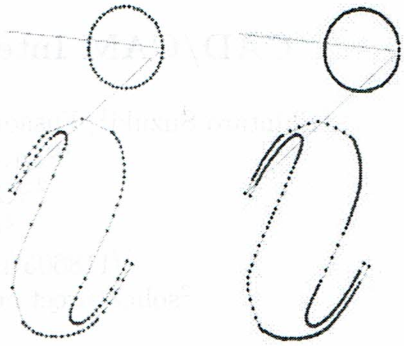

Figure 3: Original CLS data of outline font "i" and interpolated ones.

distance $\boldsymbol{P}_{k-i}\boldsymbol{P}_k$ between adjacent original points in the CLS data is smaller than maximum distance $d_{\max}$ set in advance. When these two conditions are simultaneously satisfied, interpolation points are generated. For preparation of the evaluation experiment, CLS data of an outline font (Elephant "Yamaguchi") was created using Illustrator and Creo. The above interpolation algorithm was applied to this data. The number of interpolation points by the spline curve was set to three; the angle θ_k was set to 120 degrees, and the maximum distance $d_{\max}$ between two adjecent GOTO statements in CLS data was set to 40 mm. Also, the deletion condition of a GOTO statement was set to 0.8 mm in order to prevent deformation at spline interpolated points where the distance between two adjacent GOTO statements is very close. In other words, this is a function to delete a GOTO statement if the distance between the target two GOTO statements is smaller than the specified value $d_{\max}$. By applying these generation conditions, smart interpolated CLS data can be created. Figure 3 shows the comparison of CLS data before and after interpolation of Elephant "i" which is an outline font.

3 CAD/CAM Interface for Educational Robot DOBOT

Recently, this robot with four degrees of freedom has been receiving much attention in the field of mechatronics education. Despite its low cost, it can be used for additive manufacturing like a 3D printer, cutting using an end mill, printing with a pen tool, laser processing and so on. Mass and payload of the robot are 3 kg and 500 g respectively, which can be controlled by a PC or smartphone. Also, the position repeatability of this educational robot is 0.2 mm, which is excellent as an industrial robot. However, since some interface with CAD/CAM systems seemed to be not provided, we considered the functions that can be associated with them [3]. As a first step, we implemented a basic motion controller using DOBOT API for MFC (Microsoft Foundation Class) on Visual Studio 2017 which is an integrated development environment being popular among students. The API is an interface used for mutual input/output operation of software components, and is a device driver which enables sharing of functions with other software.

In this study, we developed a dialog-based CAD/CAM interface mainly using two functions to access the DOBOT, GetPose( ) to obtain position information and GotoPoint( ) to move to a desired position. The GetPose( ) can obtain the position coordinates and the orientation angle of the current arm tip. GotoPoint( ) can move the arm tip with a PTP(Point to Point) mode or CP(Continous Path) mode to the specified next position. Figure 4 shows DOBOT with a CAD/CAM interface that can be executed interpretively. To check the effectiveness of the interface, we first converted an outline font Calibri "S" to DXF data using Illustrator and then loaded it on Creo. Next, CLS data along the outline font are created using the main processor of the CAM in Creo and segments between two adjacent points in the CLS data are interpolated with three points as shown in Figure 5 using the spline interpolation function proposed in the previous section. Any work coordinate system can be set using the developed dialog-based CAD/CAM interface, i.e., by designating the position obtained by GetPose( ). The proposed interpreter-like controller can analyze CLS data line by line, so that extracted position data can be given to the DOBOT using the GotoPoint( ).

A drawing experiment is conducted to check the effectiveness of the developed CAD/CAM interface. As mentioned above, Calibri"S" is firstly designed using Illustrator then the converted DXF file is retrieved into Creo. The CAM of Creo generates the corresponding CLS data of the outline font. Figure 6 shows a successful drawing scene of the Calibri font "S", in which the generated CLS data are successively being given to the

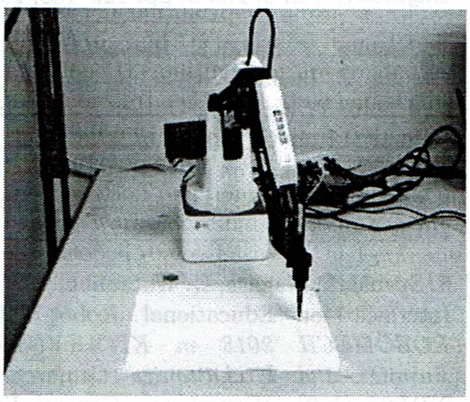

Figure 4: Educational robot DOBOT incorporated with the developed CAD/CAM interface.

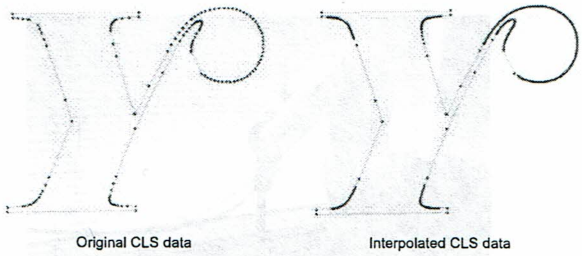

Figure 5: Original CLS data of outline font "Y" and interpolated ones.

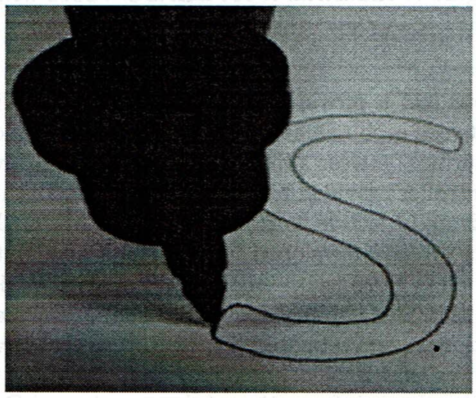

Figure 6: Drawing scene of Calibri font "S".

DOBOT. It is confirmed from the result that the proposed CAD/CAM interface can work for teaching-less operation.

4 CAD/CAM Interface for an Industrial Robot DENSO VS068

In this section, a CAD/CAM interface for an industrial robot DENSO VS068 is proposed. Figure 7 shows the industrial robot DENSO VS068. The robot provided by DENSO is a typical industrial manipulator with 6-DOFs. The maximum payload at the arm tip is 7 kg. This robot can be equipped with a spindle motor, and it is possible to develop applications using ORiN (Open Resource interface for the Network). ORiN is a communication interface for standardization that provides unified access means and representation methods for various devices. It is a standard specification for accessing information in a common way on different control devices such as manufacturers, old and new versions, robots and NC machine tools from the same application software and is put to practical use due to ORiN2 SDK.

when developing robotic applications, the authors found that it is important to use a standard interface called CAO (Controller Access Object). The CAO consists of an engine part that gives common func-

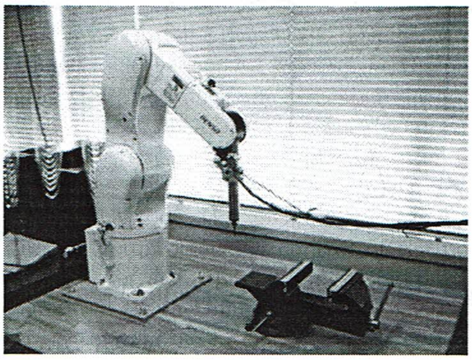

Figure 7: Industrial robot DENSO VS068 with ORiN.

tions and a provider part that absorbs the difference between each manufacturer. It functions as a common interface between a higher application and a lower level controller provided by the manufacturer. In this study, it is an objective to transplant the CAD/CAM interface already developed for the small articulated-type robot "VE026" with ORiN to the VS068. Which functions in CAO library should be used for the transplantation was investigated [11, 12, 13], so that it was confirmed that CaoGetPose( ) for monitoring the position and attitude information of the arm tip and CaoMove( ) giving the target position and attitude information to the servo system are important. In order to verify the usefulness of the CAD/CAM interface implemented for the VS068, the authors performed experiments on trajectory tracking control of the position and attitude of the arm tip by setting a tool path (CLS data) generated by the main processor of Creo. The target trajectory, i.e., CLS data, is based on "Yamaguchi" which is an outline font Elephant created with the Illustrator. The desired position and attitude every sampling period were calculated based on the CLS data and given to the servo system via the CaoMove( ) function. As a result, the tip of the robot arm was able to be controlled along the tool path generated by the Creo. Figure 8 and 9 show the engraving scene and the engraved result of Elephant "Yamaguchi".

5 Conclusion

In this study, CAD/CAM interfaces are proposed for two types of articulated robots. Due to the interfaces, the robots could draw and engrave outline fonts designed by Illustrator without a complicated teaching task. Through actual experiments, the usefulness of the CAD/CAM interfaces was confirmed, so that desirable robotic teaching-less operations could be realized.

In future work, the authors are planning to demonstrate another function on how reverse engineering using a depth sensor such as Intel RealSense will be realized.

Figure 8: Engraving scene of Elephant font "Yamaguchi".

Figure 9: Engraved result of Elephant font "Yamaguchi".

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