Engineering, 2022, 14, 371-384
https://www.scirp.org/journal/eng
ISSN Online: 1947-394X
ISSN Print: 1947-3931

An Advanced Control Technology Robotic Casting and Glazing for Ceramic Bowls

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How to cite this paper: Muangmeesri, B. and Maneetham, D. (2022) An Advanced Control Technology Robotic Casting and Glazing for Ceramic Bowls. *Engineering*, **14**, 371-384.
https://doi.org/10.4236/eng.2022.148029

Received: April 26, 2022
Accepted: August 28, 2022
Published: August 31, 2022

Abstract

Glazes on ceramics provide a durable finish as well as a protective layer, impervious, sanitary, and generally easily cleaned surface, have the advantage of having a very wide spectrum of colors. As a result, color has a lot of variability, luminosity and permanence. This method of coating is suitable for products that are not too big a smooth and can be done quickly such as plating of coffee mugs, cups or bowls. Putting the product in the enameled tank must not be soaked for too long as it will thicken the coating. When the coating is dry it will slip off easily. Therefore, this research is to provide product dipping. Good and consistent plating at all times and then industrial robots are used to help in plating or dipping. The robot can control the work quickly. According to the position and speed control can reduce the working time in the further.

Keywords

Ceramic, Clay and Glazes, Automation, Industrial Robotics

1. Introduction

There are many ways to go about the development of the ceramic surface, some no-tech, some low-tech, and some high-tech. The great thing about glaze development is that you can choose your personal approach at whatever lever you feel comfortable. Many well-known potters absolutely hate to deal with calculation in any way and do all of their glaze and color development by purely empirical processes of trying it and seeing [1] [2]. They usually get to know a small number of favorite materials quite intimately and develop their palette and surface variation within fairly tight parameters. There is nothing wrong with this way of working. It has been in use for at least 5000 years, and chemical calculation processes for only a little over a hundred years. People are often inhibited by the combination of chemistry, mathematics, and analytical methods. As for the temperature used for glaze, it can be divided into three types. 1) Low temperature glaze will use a temperature about 800 - 1100 degree Celsius, 2) medium temperature glaze will use a temperature about 1150 - 1200 degrees Celsius, and 3) high temperature glaze will use a temperature about 1230 - 1300 degrees Celsius [3]. Therefore, before applying ceramic products to glaze, they should be cleaned first. Particularly if the product is left for a long time, dust will settle on the surface of the product. If using ceramic products to glaze at all. This will cause the coating to slip off the surface of the product. After that a damp sponge will be used to wipe the surface of the product one more time. After this the product is coated in the glazing process of this product. There are two types of products which are raw material condition and raw burnt [4] [5]. Therefore, the glaze that will be used to coat ceramic products must be adjusted by the glaze that will be used to coat the products in the raw material condition. The specific gravity of the glaze is about 1.4 for the finished product will use a coating with a specific gravity of about 1.7 - 1.9.

Overall, this research will explain an advanced control technology robotic casting and glazing for ceramic bowls. Properties of ceramics are explained in Section II. Section III will present the industrial robotics and calculations. Section IV validation and experimental results by comparing with speed and position control and conclusions are shown in Section V.

2. Properties of Ceramic

The method of ceramic bowls which supply more than one oxide to the glaze will be clarified by another example involving both clay and glaze [6]. Suppose the goal is to compute the recipe of the alkaline, neutral and acidic with the meaning formula given (**Table 1**).

Table 2 is represented in the raw material glaze by formulas that are identical with the empirical formula of glaze already referred. The alkalines and alkaline piles of the earth are grouped in the first column, which equals one, and the potassium oxide, calcium oxide, magnesium oxide, barium oxide and zine oxide are given values based on the first column values [7] [8]. The formula for glaze, or any other material for that matter, is determined in the same way as the formula for a glazed hatch was computed in the previous example (**Figure 1**).

Table 1. Glaze formula for ceramics.

Alkaline	Neutral	Acidic
0.25 K_2O		
0.50 CaO		
0.10 MgO	0.65 Al_2O_3	2.80 SiO_2
0.10 BaO		
0.05 ZnO		

Figure 1. Mixer machine.

Table 2. Glaze formula.

Raw Material	Percentage Recipe
$K_2O{\cdot}Al_2O_3{\cdot}6SiO_2$	44.46%
$C_aCO_3{\cdot}MgCO_3$	6.90%
$CaCO_3$	12.77%
$BaCO_3$	6.3%
ZnO	1.30%
$Al_2O_3{\cdot}2SiO_2{\cdot}2H_2O$	8.20%
SiO_2	21.07%

Soil preparing process, It starts by preparing the soil using a semi-wet mix in a pugmill or sometimes in a dry mill where the consistency of the soil during mixing is less than the wet mix. Therefore, the production by this method does not use too many raw materials. Most of the time, only clay and kaolin or chamotte are used as a filter. In a pugmill or dry mill, water is added to adjust the moisture content of the soil. After that, it will be passed through a roller to crush the rubber. The gravel mixed with the soil is broken off by the roller ser, but the distance of the roller is gradually controlled so that the rubber can be crushed of all sizes and stored in the next silo (Figure 2 and Figure 3).

The formula of the weight in terms of the relative quantities of molecules of the various method for controlling glazes can be found in the weight of water and the weight of soil [9] [10]. The quantity of each value in the formula is multiplied by the molecular weight of the soil to generate the formula weight, and the sums are tallied as follows:

(a) (b)

Figure 2. Heavy clay machine. (a) Pugmill; (b) Roller mill.

Figure 3. Dry pan mill.

$$P = K\left(\frac{R}{100}\right)(C - 0.001) \tag{1}$$

where P = glaze value (g/cm^2)

C = value of coherence (g/cm^2)

K = continuous deposition

R = receptivity of the body (g $H_2O \times 10^4/cm^2$)

0.001 = water of coherence value (g/cm^2)

The arithmetic involved in this easy calculation will be made from evident if the computation is organized in a tabular style, with all oxides in the formula and their quantities listed across the top and arranging the raw materials to be used in satisfying the formula. When calculating glazes, a table like this is commonly used to keep track of the amount of various oxides supplied by the raw ingredients (Table 3).

Table 3. Comparing four glaze composition.

Cone No.	Temp.	Composition					
		K_2O	M_gO	C_aO	B_3O_3	Al_2O_3	SiO_2
1	1080˚C 1978˚F	0.06	1.3	0.42	0.6	0.3	2.8
2	1200˚C 2192˚F	0.2	0.1	0.7	0.1	0.46	3.5
3	1230˚C 2246˚F	0.2	0.1	0.7	-	0.4	3.5
4	1410˚C 2570˚F	2.8	1.3	6.6	11.6	8.4	46.5

3. Methodology

The inverse and forward kinematics problem deals with the determination of the position and orientation of the gripper frame when the joint variable are numerically specified and the FANUC M-6i was designed to the high speed and 6 kg payload capacity some of the advantages of material handling, arc welding, dispensing, machine loading, material removal, and robotic assembly (**Figure 4** and **Figure 5**).

3.1. Link Parameters

The 6-axis robot can be driven by a computer such that the tool tip can take an arbitrary position and orientation. A FANUC M-6i frame assignment for the various links are divided into 6 links as follows: Link J1 ±165˚, Link J2 +135˚−75˚, Link J3 +150˚−149˚, Link J4 ±190˚, Link J5 ±140˚, and Link J6 ±350˚. The link parameters of a FANUC M-6i industrial robotics can be shown in **Table 4** (**Figure 6**).

3.2. Transformation Matrix

Coordinate transformations containing both rotations and translations are necessary to express the mobile tool position and orientation in terms of a coordinate frame coupled to the stationary base. Begin by exploring the representation of rotations and coordinate transformations as given as 4 × 4 matrix:

$$ {}^{i-1}A_i = \begin{bmatrix} \cos\theta_i & -\sin\theta_i\cos\alpha_i & \sin\theta_i\sin\alpha_i & a_i\cos\theta_i \\ \sin\theta_i & \cos\theta_i\cos\alpha_i & -\cos\theta_i\sin\alpha_i & a_i\sin\theta_i \\ 0 & \sin\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2} $$

thus

$$ {}^{0}T_{i-1}\,{}^{i-1}A_i\,, \tag{3} $$

where ${}^{0}T_i$ is the homogenous coordinates of a point are found i within the confines of a moveable coordinate frame 0. Verify that the resulting homogeneous coordinate transformation matrix is:

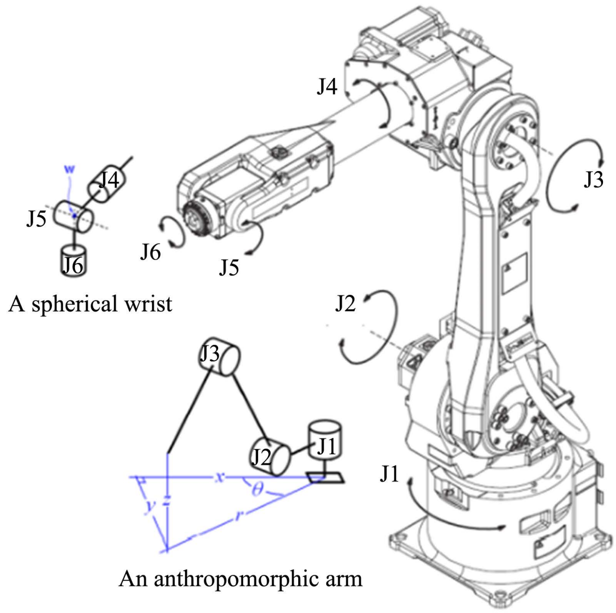


Figure 4. A FANUC M-6i industrial robotics.

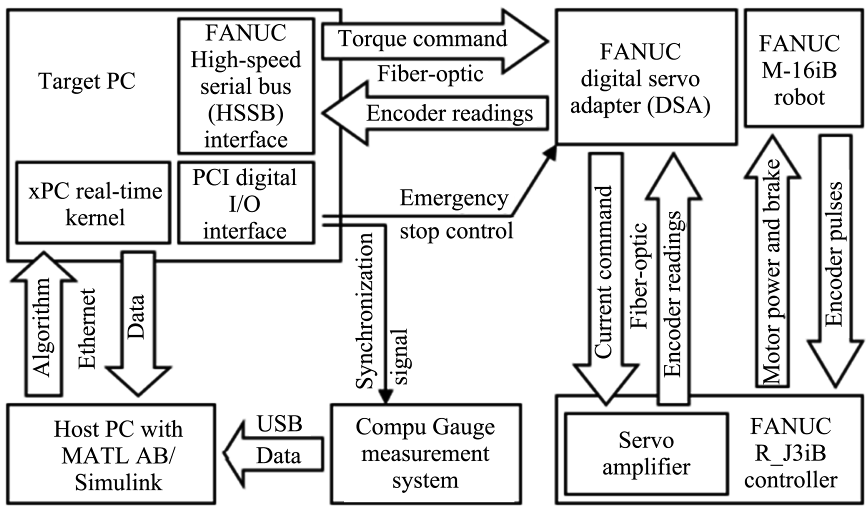
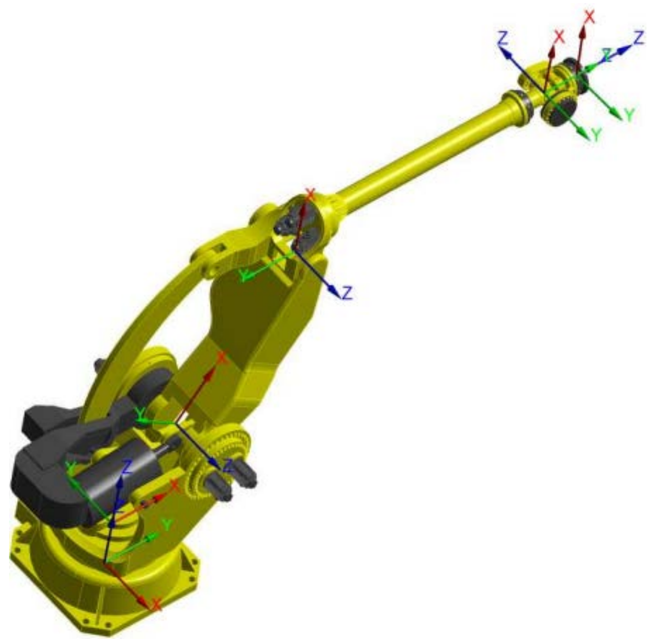


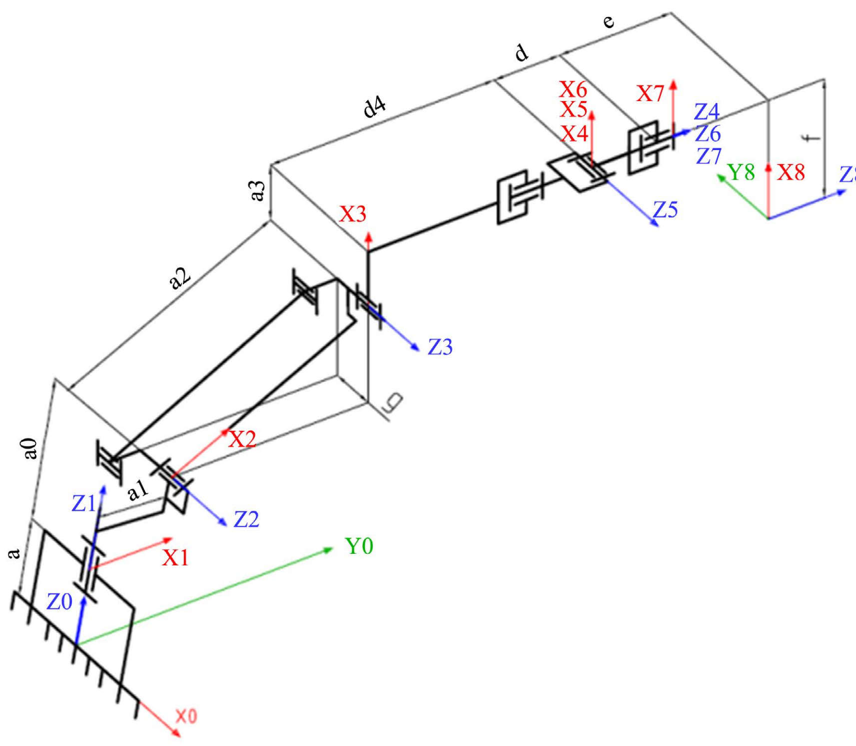
Figure 5. Control system of a FANUC M-6i.

Table 4. Link parameters for FANAC M-6i.

Axis (i)	α_i	a_i	d_i	θ_i
1	0	0	0	θ_1
2	-90°	500	0	θ_2
3	0	1700	0	θ_3
4	-90°	180	2850	θ_4
5	90°	0	0	θ_5
6	-90°	0	0	θ_6



(a)



(b)

Figure 6. The 6-axis A FANUC M-6i. (a) Robot manipulator; (b) coordinate systems.

$$^{0}T_{1}=\begin{bmatrix}\cos\theta_1 & -\sin\theta_1 & 0 & 0\\ \sin\theta_1 & \cos\theta_1 & 0 & 0\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{bmatrix} \tag{4}$$

$$^{1}T_{2}=\begin{bmatrix}\cos\theta_2 & -\sin\theta_2 & 0 & a1\\ 0 & 0 & 1 & 0\\ -\sin\theta_2 & -\cos\theta_2 & 0 & 0\\ 0 & 0 & 0 & 1\end{bmatrix} \tag{5}$$

$$^{2}T_{3}=\begin{bmatrix}\cos\theta_3 & -\sin\theta_3 & 0 & a2\\ \sin\theta_3 & \cos\theta_3 & 0 & 0\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{bmatrix} \tag{6}$$

$$^{3}T_{4}=\begin{bmatrix}\cos\theta_4 & -\sin\theta_4 & 0 & a3\\ 0 & 0 & 1 & d4\\ -\sin\theta_4 & -\cos\theta_4 & 1 & 0\\ 0 & 0 & 0 & 1\end{bmatrix} \tag{7}$$

$$^{4}T_{5}=\begin{bmatrix}\cos\theta_5 & -\sin\theta_5 & 0 & 0\\ 0 & 0 & -1 & 0\\ \sin\theta_5 & \cos\theta_5 & 0 & 0\\ 0 & 0 & 0 & 1\end{bmatrix} \tag{8}$$

$$^{5}T_{6}=\begin{bmatrix}\cos\theta_6 & -\sin\theta_6 & 0 & 0\\ 0 & 0 & -1 & 0\\ -\sin\theta_6 & -\cos\theta_6 & 1 & 0\\ 0 & 0 & 0 & 1\end{bmatrix} \tag{9}$$

$$TCPF=\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\\ 0 & 0 & 1 & d\\ 0 & 0 & 0 & 1\end{bmatrix} \tag{10}$$

$$TB=\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\\ 0 & 0 & 1 & a+a0\\ 0 & 0 & 0 & 1\end{bmatrix} \tag{11}$$

$$TEF=\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & 1 & 0 & f\\ 0 & 0 & 1 & e\\ 0 & 0 & 0 & 1\end{bmatrix} \tag{12}$$

The four-dimensional space of homogeneous can be defined as follows:

$$T=T01\cdot T12\cdots\cdot T56\cdot TCPF\cdot TB\cdot TEF=\begin{bmatrix}R11 & R12 & R13 & Px\\ R21 & R22 & R23 & Py\\ R31 & R32 & R33 & Pz\\ 0 & 0 & 0 & 1\end{bmatrix} \tag{13}$$

1) To compute of θ_1,θ_2 and θ_3 by using for Equation (13) then this operation can be using the elements of the denoted Tran (p), where:

$$Px=c1\left(a3\cdot c32-d4\cdot s23+a1+a2\cdot c2\right);$$

$$Py = s1(a3 \cdot c32 - d4 \cdot s23 + a1 + a2 \cdot c2); \tag{14}$$
$$Pz = -a3 \cdot s23 - d4 \cdot c23 - a2 \cdot s2.$$

Verify that the inverse of the fundamental homogeneous translation matrix of the equations exists at all times and is equal to:

Step 01:

$$C1 = Px,$$
$$S1 = Py, \tag{15}$$
$$t1 = \frac{\pi}{2} - a\tan 2(Py, Px).$$

Step 02:

$$K = \frac{\left[Px^2 + Py^2 + Pz^2 - 2a1\left(Px \cdot \cos(t1)\right)\right]}{2a2} + \frac{\left[Py \cdot \sin(t1) + a1^2 - \left(a3^2 + d4^2 + a2^2\right)\right]}{2a2};$$
$$t3 = a\tan 2(d4, a3) - a\tan 2\left[\left(\sqrt{a3^2 - d4^2 - \sqrt{K^2}}\right), K\right] \tag{16}$$

Step 03:

$$a = -d4 \cdot \sin(t3) + a2 + a3 \cdot \cos(t3);$$
$$b = a3 \cdot \sin(t3) + d4 \cdot \cos(t3);$$
$$c = \frac{Px}{\cos(t1)} - a1;$$
$$d = -Pz;$$
$$t2 = a\tan 2\left[(a \cdot c + b \cdot d), (a \cdot d - b \cdot c)\right]. \tag{17}$$

2) To replace the θ_4, θ_5 and θ_6 in equations (14) as given:

$$T03^{-1} \cdot T06 = T36;$$
$$T04^{-1} \cdot T06 = T46; \tag{18}$$
$$T05^{-1} \cdot T06 = T56.$$

When $T0n^{-1}$ is the element of value. The homogeneous translations can use the cartesian space equation by using in Equation (15).

$$\theta = a\tan 2(x, y)[rad]. \tag{19}$$

Then can convert the rad to deg is given by:

$$\theta_{\deg} = \theta \cdot \frac{180}{\pi} \tag{20}$$

Step 04:

$$S4 = \left[-R13 \cdot \sin(t1) + R23 \cdot \cos(t1)\right];$$
$$C4 = \left[-R13 \cdot \cos(t1) \cdot \cos(t2 + t3)\right] - \left[R23 \cdot \sin(t1) \cdot \cos(t2 + t3)\right] + \left[R33 \cdot \sin(t2 + t3)\right]; \tag{21}$$

$$t4 = \frac{\pi}{4} - a\tan 2(S4, C4)$$

Step 05:

$$s5 = -\{R13 \cdot [\cos(t1) \cdot \cos(t2+t3) \cdot \cos(t4) \cdot \sin(t1) \cdot \sin(t4)]$$
$$+ R23 \cdot [\sin(t2+t3) \cdot \cos(t4) \cdot \cos(t2+t3)\cos(t4)$$
$$- \cos(t1) \cdot \sin(t4)] - R33 \cdot [\sin(t2+t3) \cdot \cos(t4)]\};$$

$$c5 = \{R13 \cdot [\cos(t1) \cdot \cos(t2+t3) \cdot \cos(t4) + \sin(t1) \cdot \sin(t4)]$$
$$+ R23 \cdot [\sin(t2+t3) \cdot \cos(t4) \cdot \cos(t2+t3) \cdot \cos(t4)$$
$$- \cos(t1) \cdot \sin(t4)] - R33 \cdot [-\cos(t2+t3)]\};$$

$$t5 = \frac{\pi}{2} - a\tan 2(s5, c5) \tag{22}$$

Step 06:

$$s6 = R11 \cdot [\cos(t4) \cdot \sin(t1) - \cos(t1) \cdot \cos(t2+t3) \cdot \sin(t1) \cdot \sin(t4)]$$
$$+ R31 \cdot \sin(t4) \cdot \sin(t2+t3);$$

$$c6 = R12 \cdot [\cos(t4) \cdot \sin(t1) - \cos(t1) \cdot \cos(t2+t3) \cdot \sin(t4)]$$
$$- R22 \cdot [\cos(t1) \cdot \cos(t4) + \cos(t2+t3) \cdot \sin(t1) \cdot \sin(t4)]$$
$$+ R31 \cdot \sin(t4) \cdot \sin(t2+t3);$$

$$t6 = \frac{\pi}{2} - a\tan 2(s6, c6) \tag{23}$$

4. Experimental and Results

As in the cause writing that on the surface of the product such as scribbling, parallel grooving, carving various patterns are formed on the surface of the produce. In addition to finishing the product before burning it. So the product bowl before the glaze is dipped, different designs must be written on the side of the bowl as shown in Figure 7.

(a) (b)

Figure 7. A bowl for preparing to paint. (a) Chicken picture; (b) stored bowl.

After that, the bowl will be placed on the belt conveyor. The bowl will be conveyed from the conveyor and sensor detects and sends a signal to the robot. The robotic manipulator can hold the bowl in the gripper position (Figure 8 and Figure 9).

Finally, when the robot finishes taking a bowl of glazed water. The bowl will be placed in position on the output belt conveyor (Figure 10).

Consider the FANUC M-6i manipulator can be shown in Figure 11. This is a six-axis articulated robot with a spherical wrist with a roll-pitch, roll type. Using the first half of the D-H algorithm, assign connection coordinates. The motion control of the end-effector on all three axes, namely axis-x, axis-y, and axis-z, will be tested to position and speed control of movement. A total of 30 tested were conducted and results as shown in Table 5.

Figure 8. Robotic glazing for ceramic bowl (step 1).

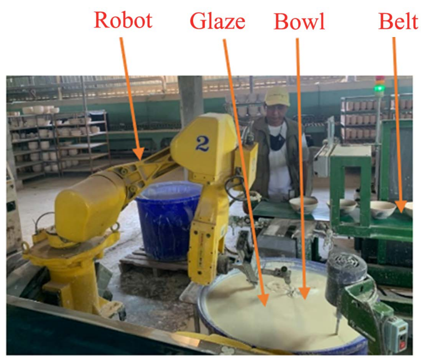


Figure 9. Robotic glazing for ceramic bowl (step 2).

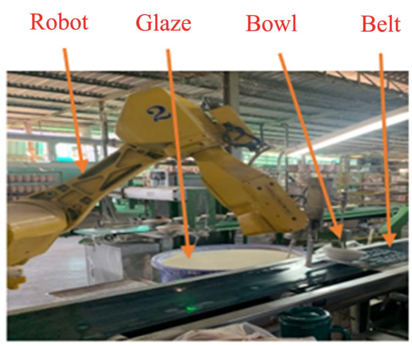


Figure 10. Robotic glazing for ceramic bowl (step 3).

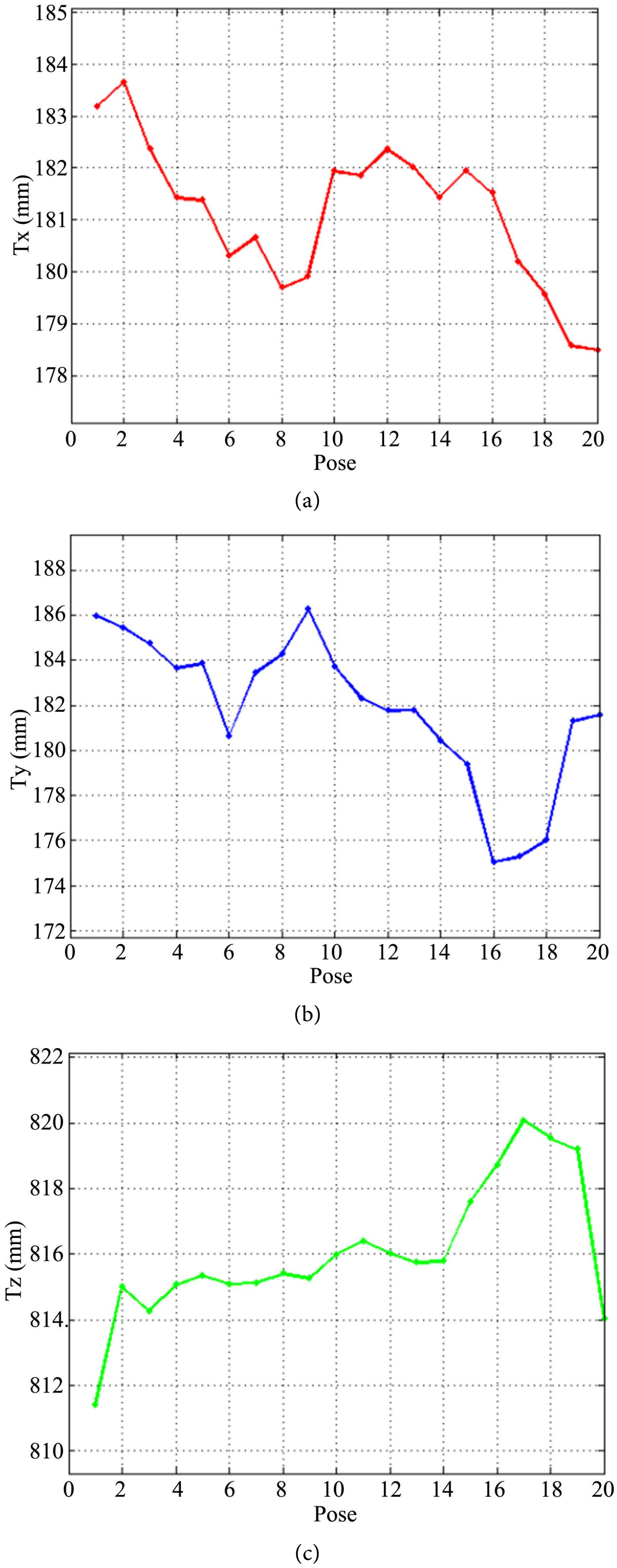


Figure 11. Link the end-effector calibration at 3 axes. (a) Translation at x-axis; (b) translation at y-axis; (c) translation at z-axis.

Table 5. Link the end-effector calibration.

Axis	Average Value	Variance	Standard Deviation
x (mm)	192.4573	1.8669	1.3128
y (mm)	192.6582	12.0436	3.4265
z (mm)	965.0345	5.3257	2.0907

Finally, as a solution of a complete dynamic model of a robotic arm, consider the FANUC M6i robot shown in Figure below. To compare with the position, orientation and translation are displayed to control the motion for guidance.

5. Conclusion

This research has proposed the development of FANUC M-6i the articulated robotic arm by using angle configuration $\theta_1, \theta_2, \theta_3, \theta_4, \theta_5, \theta_6$. The robotic arm has proposed that based on FANUC RJ2 controller interface and the kinematics of robotics has been designed with the Denavit-Hartenberg model method. For Figure 11, the control of the end-effector on all three axes has the same standard deviation. A total of 30 test runs of holding the bowl to be immersed in the enamel tank were 1.3128 in the x-axis, 3.4265 in the y-axis, and 2.0907 in the z-axis. The pieces help for precise immersion in the coating and reduce the amount of waste and reduce the working time in a ceramic plant as well.

Acknowledgements

We acknowledge of the P. Ceramic company, Lampang Province, Thailand supported and helped in this research.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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