A Camera-based Tool Pose Measurement Method for Automatic Tool Insertion for Emergent Operation of Fuelling Machine

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1. Introduction

Refuelling operations are carried out on power with the aid of two fuelling machines in pressured heavy water reactor (PHWR) system. Two fuelling machines clamp on the two end-fitting on each side of fuel channel and new fuel bundles are pushed from the upstream fuelling machine and spent fuel bundles are taken out into the downstream fuelling machine. The ram assembly of the fuelling machine pushes fuel bundles and operates the shield and closure plugs in each fuel channel, the snout plug in the fuelling machine snout, and the guide sleeve tool [1]. In spite of periodic maintenance, there are some possibilities for the hydraulic drives of the ram to malfunction during their operation and the manual drive handles are provided to fix such problems. But in some cases the plant should be shutdown to be fixed because high dose rate inhibits the access of human workers.

To mitigate such an event, KAERI developed a remotely-operated robotic system [2]. The robotic system operates the manual drive handles for B ram and Latch ram to release the fuelling machine from the fuel channel. On-site experiments were performed successfully by KAERI and KHNP at Wolsong nuclear power plant as shown in Fig. 1 during overhaul in 2007.

Fig. 1. On-site Experiment

In order to align its tools to the manual drive handles the operator should monitor video images from cameras in several view points and recognize the relative position between the tools and the target positions as shown in Fig. 2.

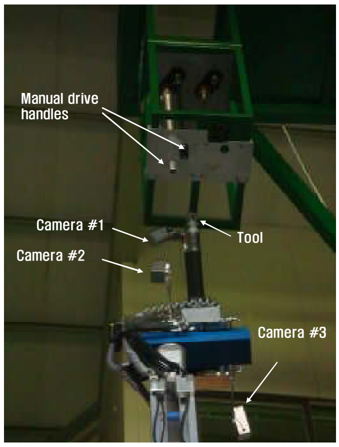

Fig. 2. Test Mock-up

Fig. 3 shows an image captured from camera #2. As shown in this figure, each shape of the manual drive handle and tool can be modeled as a cylinder with two circular ends.

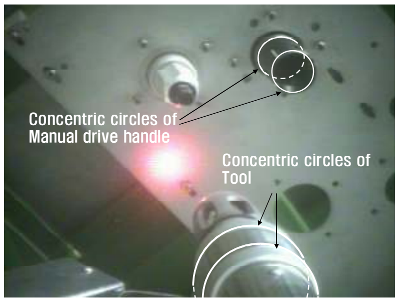

Fig. 3. Shapes of manual drive handle and tool

Thus in this study, we applied a camera calibration method that obtains the relative position and orientation of cylindrical object based on its radius and height [3].

From the relative position and orientations of the manual drive handle and the tool with respect to camera, we obtained the resultant relative position and orientation between the manual drive handle and the tool. Simulation results are also provided to verify the applicability the proposed method.

2. Methods and Results

2.1 Camera calibration using a cylindrical object

In Fig. 4, C_1 and C_2 denote the circles of the lower ends of a cylinder with radius r and are located on two parallel planes, π_1 and π_2 respectively. The origin of the coordinate system $\{x_w, y_w, z_w\}$ is located at the center point of C_1 denoted by O_1 and the direction of the z_w-axis is normal to π_1. O_2 is represented with respect to the coordinate system $\{x_w, y_w, z_w\}$ as $[0,0,d]^T$.

We use a pin-hole camera model [3] and denote a camera coordinate system by $\{x_c, y_c, z_c\}$, the image forming process can be modeled as follows.

$$\begin{bmatrix} x_c \\ y_c \\ z_c \\ 1 \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_x \\ r_{21} & r_{22} & r_{23} & t_y \\ r_{31} & r_{32} & r_{33} & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix} \equiv \begin{bmatrix} \widetilde{R}_{CW} & T_{CW} \\ 000 & 1 \end{bmatrix} \begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix} = H_{CW} \begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix} \quad (1)$$

$$\widetilde{R}_{CW} \equiv [r_1\ r_2\ r_3] = Rot(z, R_z)Rot(y, R_y)Rot(x, R_x) \quad (2)$$

$$z_f \begin{bmatrix} x_f \\ y_f \\ 1 \end{bmatrix} = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_c \\ y_c \\ z_c \end{bmatrix} = \widetilde{K} \begin{bmatrix} x_c \\ y_c \\ z_c \end{bmatrix} \quad (3)$$

In Eq. (1), $\widetilde{R}_{CW}$ a is 3x3 rotation matrix and T_{CW} is a 3x1 translation vector between $\{x_w, y_w, z_w\}$ and $\{x_c, y_c, z_c\}$ corresponding to camera pose information w.r.t. the world coordinates. H_{CW} is the homogeneous coordinate transformation matrix between the camera and world coordinates

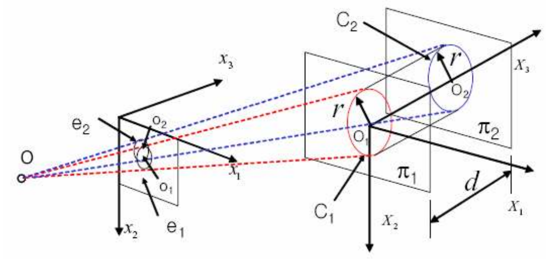

Fig. 4. Image Formation of Cylindrical Object

The circles C_1 and C_2 are observed as elliptic images referred by e_1 and e_2 as shown in Fig. 4. From the elliptic equations of e_1 and e_2, we can obtain the rotation matrix and the translation matrix using the camera calibration method using a cylindrical object [3].

2.2 Tool Pose Representation

Resulting from the method as briefly described above section, we denote the homogeneous coordinate transform matrixes by the following equations.

$$\begin{bmatrix} x_c \\ y_c \\ z_c \end{bmatrix} = H_{CT} \begin{bmatrix} x_T \\ y_T \\ z_T \\ 1 \end{bmatrix}, \quad \begin{bmatrix} x_c \\ y_c \\ z_c \end{bmatrix} = H_{CH} \begin{bmatrix} x_H \\ y_H \\ z_H \\ 1 \end{bmatrix} \quad (4)$$

Thus we can get the tool pose relative to the handle as follows:

$$\begin{bmatrix} x_T \\ y_T \\ z_T \\ 1 \end{bmatrix} = H_{TH} \begin{bmatrix} x_H \\ y_H \\ z_H \\ 1 \end{bmatrix}, \quad H_{TH} = H_{CT}^{-1} H_{CH} \quad (5)$$

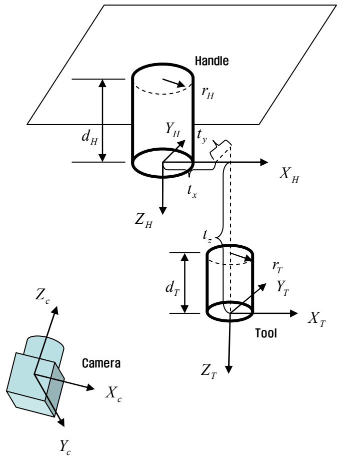

Fig. 5. Coordinate Systems

2.4 Simulation Results

We calculated the tool positions for some synthesized images by simulations. As shown in Table I, the calculated errors are about 10mm when the tool approaches the handle. .

Table I: Calculated Handle Position

	Given(mm)			Calculated(mm)		
	t_x	t_y	t_z	t_x	t_y	t_z
1	0	0	600	2.4	-17.8	593.0
2	0	0	500	2.0	-15.4	493.9
3	0	0	400	1.6	-12.9	394.8
4	0	10	400	1.6	-1.7	395.2
5	0	20	400	1.6	9.7	395.6
6	10	20	400	15.7	14.8	397.6
7	20	20	400	29.8	15.7	397.5

3. Conclusions

In this paper, we provided a measurement method for the relative position and orientation between the cylindrically shaped target and tool. From simulation results, we showed the applicability of the proposed method for automatic operation of he manual drive handle of the ram assembly in fuelling machine.

As further works, we will setup a mock-up environment and implement visual serving algorithm based on the proposed measurement method.

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