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The Arm Equation and Reliability of 6-DOF KUKA Robot

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Abstract

In this paper the arm equation of 6-axes articulated KUKA robot [KR-16] is derived using Denavit-Hartenberg algorithm. Given an explicit task to be executed, a robot might be used to find the probability of success or reliability. Here, an experimental set up has been established and reliability is evaluated from experimental data. Moreover, a relationship between reliability and repeatability of robot is established.

Keywords: *Forward Kinematics, KUKA Robot, Reliability.*

I. Introduction

In order to benefit from robotic technology, reliability should be considered a major portion of investment decisions. Robotic systems are complex. Thus uncertainty cannot be avoided. The reliability of robot can be found by either of the following methods:

1. In terms of previous failure data of robot.
2. In terms of component of the robot.
3. In terms of the performance of the robot.

In this paper, we have found out reliability of the robot in terms of its performance.

In this paper the kinematics modeling of KR-16 KUKA robot as shown in Fig.1 is carried out and reliability is found experimentally. The various dimensions of KR-16 robot is shown in Fig.2. Generally, KUKA Robotics is a leading German producer of industrial robots for a variety of industrial processes like welding, painting etc. The robotic arm comes with a control panel that has a display and an integrated mouse, with which the manipulator is moved, positions are saved, or where modules, functions, and data lists are created and modified. Controls for the latest control panel use the Windows XP operating system. The KR-16 is a 6-axes robotic arm weighting 235 kg with the payload up-to 16 kg. [11].

II. The Arm Equation

Using DH algorithm, the different frames are developed in Figures 3 (a), (b), (c), (d), (e), (f) and (g) and kinematic table showing different parameters is prepared [9]. The kinematic table of 6-axes robot is shown in Table1:

Table1: Kinematic Table

i	θ	d	a	α
1	q_1	675mm	260 mm	-90^0
2	q_2-90^0	0mm	680 mm	0^0
3	q_3	0mm	0 mm	90^0
4	q_4	-670mm	0 mm	-90^0
5	q_5	0 mm	0 mm	90^0
6	q_6	-158 mm	0 mm	180^0

The arm equation is then derived as follows:

$$T = T_0^1 T_1^2 T_2^3 T_3^4 T_4^5 T_5^6$$

Where general forms of T_{k-1}^k is given as

$$T_{k-1}^k = \begin{bmatrix} C\theta_k & -C\alpha_k S\theta_k & S\alpha_k S\theta_k & a_k C\theta_k \\ S\theta_k & C\alpha_k C\theta_k & -S\alpha_k C\theta_k & a_k S\theta_k \\ 0 & S\alpha_k & C\alpha_k & d_k \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

So, first we determine

$$T_0^1 = \begin{bmatrix} C_1 & 0 & -S_1 & a_1C_1 \\ S_1 & 0 & C_1 & a_1S_1 \\ 0 & -1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_1^2 = \begin{bmatrix} C_2 & -S_2 & 0 & a_2C_2 \\ S_2 & C_2 & 0 & a_2S_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$T_2^3 = \begin{bmatrix} C_3 & 0 & S_3 & 0 \\ S_3 & 0 & -C_3 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_3^4 = \begin{bmatrix} C_4 & 0 & -S_4 & 0 \\ S_4 & 0 & C_4 & 0 \\ 0 & -1 & 0 & d_4 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_4^5 = \begin{bmatrix} C_5 & 0 & S_5 & 0 \\ S_5 & 0 & -C_5 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_5^6 = \begin{bmatrix} C_6 & S_6 & 0 & 0 \\ S_6 & -C_6 & 0 & 0 \\ 0 & 0 & -1 & d_6 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The total transformation between the base of the robot and the tool is

$$T_{base}^{tool} = T_0^1 T_1^2 T_2^3 T_3^4 T_4^5 T_5^6$$
$$= \begin{bmatrix} n_x & O_x & a_x & p_x \\ n_y & O_y & a_y & p_y \\ n_z & O_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Where

$$n_x = C_1C_{23}(C_4C_5C_6 - S_4S_6) - S_1(S_4C_5C_6 + C_4S_6)$$
$$- S_5C_6C_1S_{23}$$

$$n_y = S_1C_{23}(C_4C_5C_6 - S_4S_6) - S_5C_6S_1S_{23}$$
$$+ C_1(S_4C_5C_6 + C_4S_6)$$

$$n_z = -S_{23}(C_4C_5C_6 - S_4S_6)$$
$$- S_5C_6C_{23}$$

$$o_x = C_1C_{23}(C_4C_5S_6 + S_4C_6)$$
$$- S_1(S_4C_5S_6 - C_4C_6) - S_5S_6C_1S_{23}$$

$$o_y = S_1C_{23}(C_4C_5S_6 + S_4C_6)$$
$$+ C_1(S_4C_5S_6 - C_4C_6)$$
$$- S_1S_{23}S_5S_6$$

$$o_z = (C_4C_5S_6 + S_4C_6)(-S_{23})$$
$$- S_5S_6C_{23}$$

$$a_x = C_1C_{23}(-C_4S_5) + S_1S_4S_5)$$
$$- C_5C_1S_{23}$$

$$a_y = S_1C_{23}(-C_4S_5) - C_1S_4S_5$$
$$- C_5S_1S_{23}$$

$$a_z = S_{23}C_4S_5 - C_5C_{23}$$

$$p_x = C_1C_{23}C_4S_5d_6 - S_1S_4S_5d_6$$
$$+ C_1S_{23}(C_5d_6 + d_4)$$
$$+ a_2C_1C_2 + a_1C_1$$

$$p_y = C_4S_5d_6S_1C_{23} + C_1S_4S_5d_6$$
$$+ (C_5d_6 + d_4)S_1S_{23}$$
$$+ a_2S_1C_2 + a_1S_1$$

$$p_z = -S_{23}C_4S_5d_6$$
$$+ C_{23}(C_5d_6 + d_4) - a_2S_2 + d_1$$

At home – position

$$\theta_1 = 0^0, \theta_2 = -90^0, \theta_3 = 0^0$$

$$\theta_4 = 0^0, \theta_5 = 0^0, \theta_6 = 0^0$$

So, at home position:

$$T_{base}^{tool} = \begin{bmatrix} 0 & 0 & +1 & -(d_4 + d_6) + a_1 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & d_1 + a_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Thus

$x^0 = z^6$

$y^0 = - y^6$

$z^0 = x^6$

Which is verified by the Figure 3(a) and Figure 3(g)

III. Experimental Set-Up

In our experimental set up we have tried to find the reliability of the robot in terms of its performance. The flowchart for calculating reliability is given in Appendix A. To perform experiment on an industrial 6-axes KUKA robot, the following three steps are prerequisite:

1. Mastering of robot.
2. Tool Calibration
3. Base Calibration

In order to find reliability the following procedure is used :

1. The mastering of robot is done with the help of EMT.
2. The tool calibration of the robot is done by XYZ – 4 point method.
3. Activate the tool by programming.
4. The base calibration of the robot is done by “3 – point” method.
5. Activate the base by programming (Ex – Base 7).
6. The robot is now programmed and moved to a point (the centre of a circle) in base 7 as shown in Figure 4 and Figure 5.

The tool is brought from home position to the centre of the circle in accordance with the programme given in Appendix B. The experiment is performed at 75% of the rated speed (2m/sec) and 40,000 observation are taken. The time taken to perform the experiment is 13 hours 20 minutes.

IV. Observations and Results

The robot is intercepted for once in total number of observations. So reliability is calculated as follows:

$$R = \frac{N_s}{N}$$

$$= \frac{39999}{40000} = .999$$

V. Conclusion

The given repeatability of the KR-16 robot is $\pm$ .05 mm and the calculated reliability of this robot is .999. We conclude that high value of repeatability or low repeatability index ensures high reliability.

Fig.1-Axes KUKA Robot

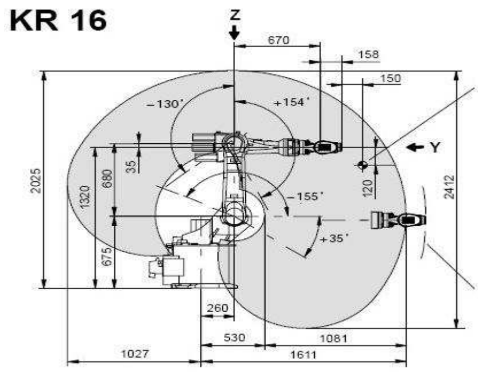

Fig.2: Dimensions of 6 Axes KUKA Robot

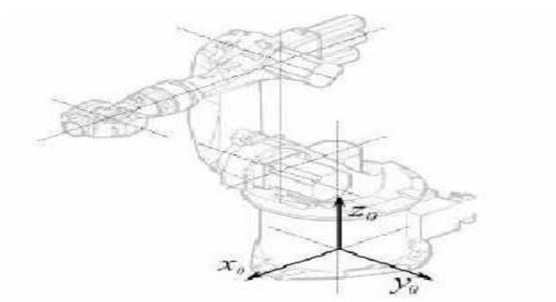

Fig. 3(a)

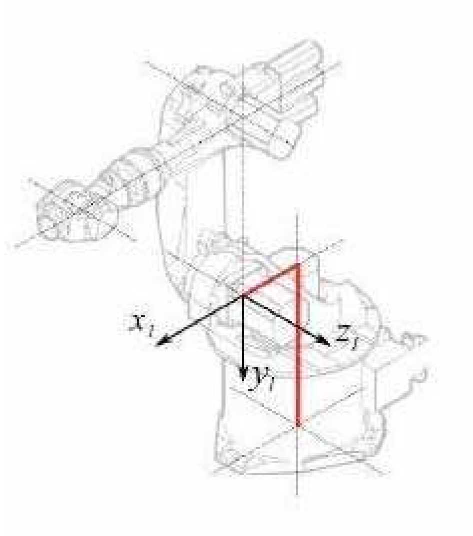

Fig. 3(b)

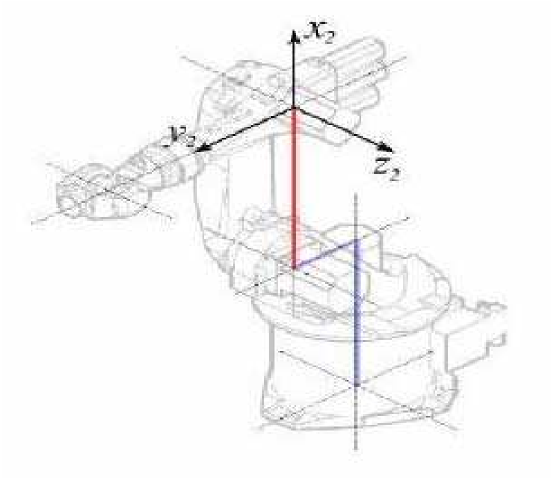

Fig. 3(c)

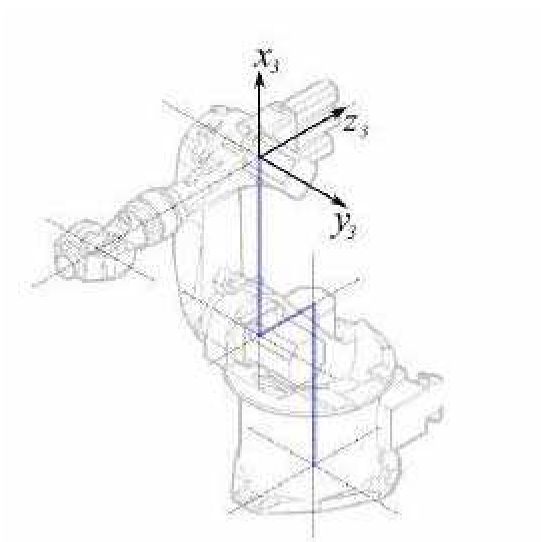

Fig. 3(d)

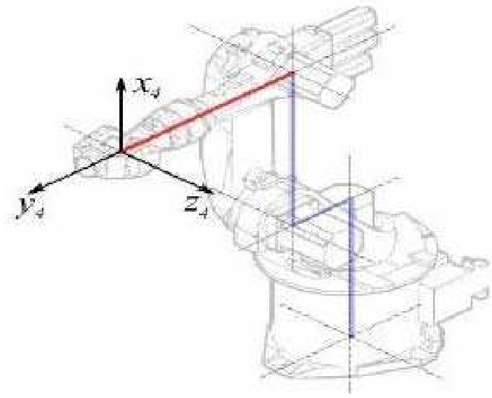

Fig. 3(e)

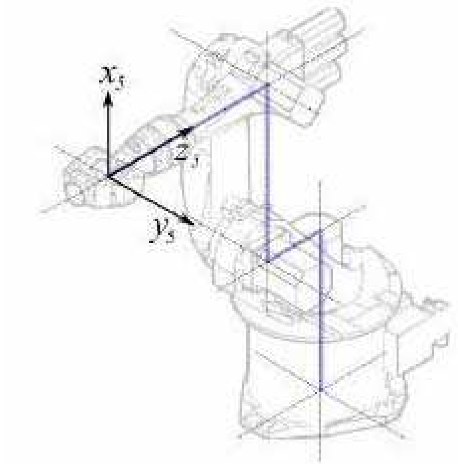

Fig. 3(f)

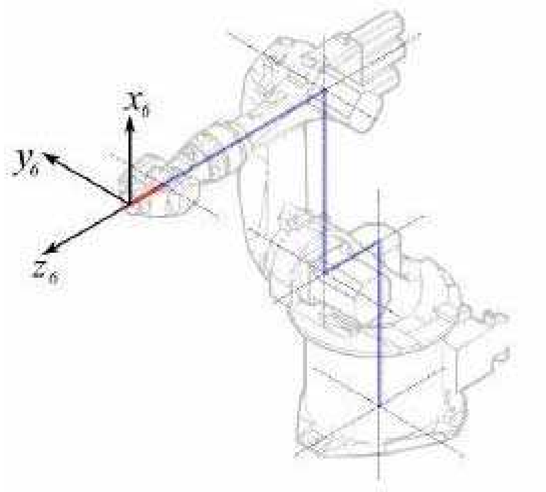

Fig. 3(g)

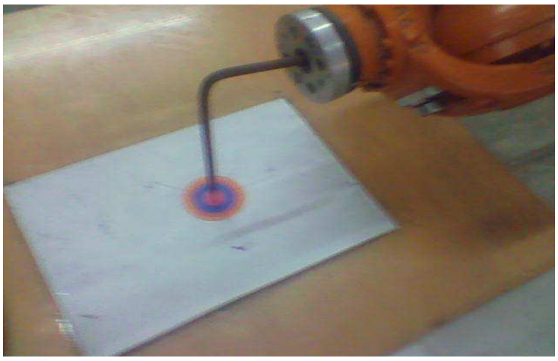

Fig.4

Fig.5

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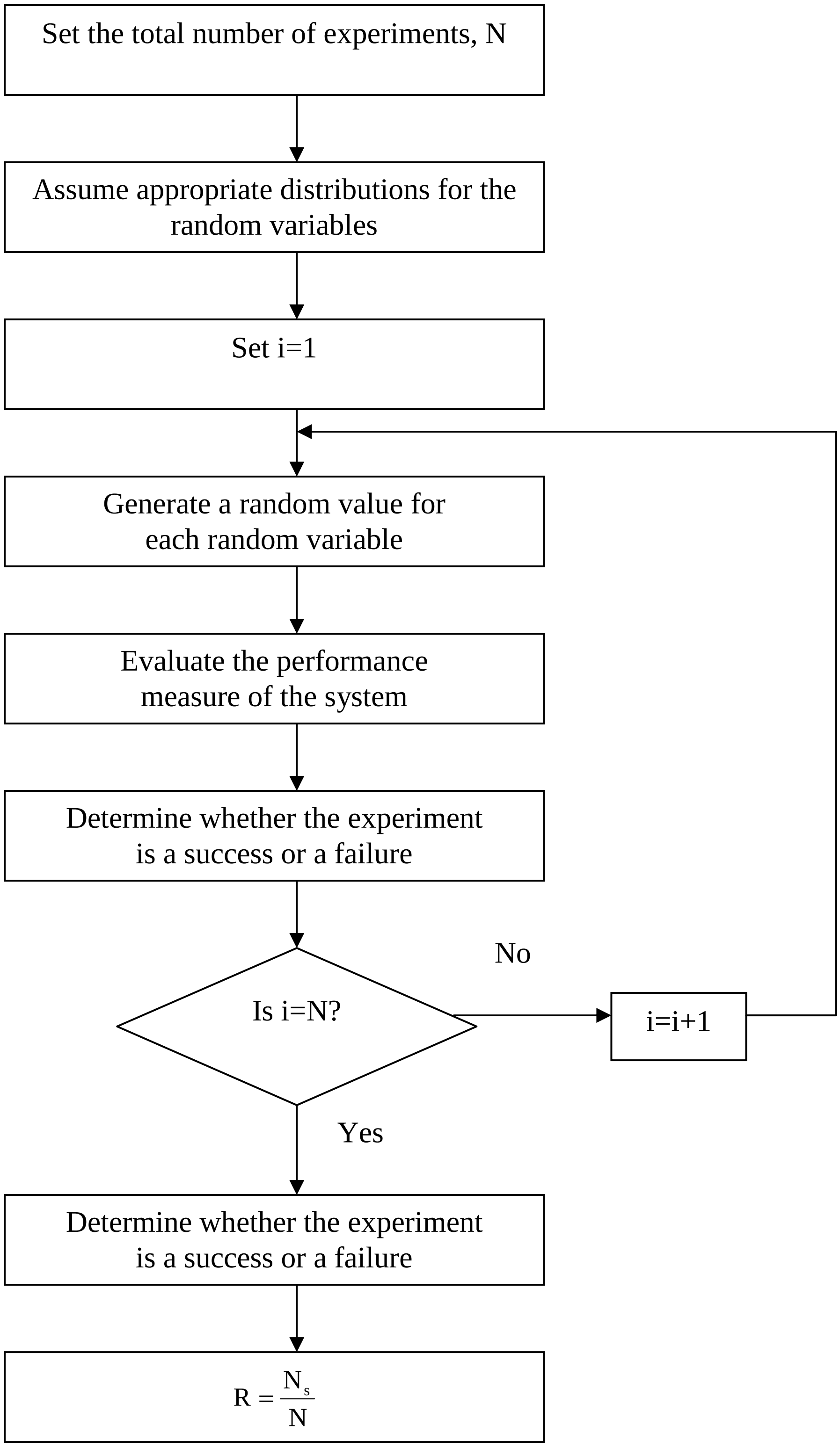
Flow Chart

APPENDIX- A



Where R=Reliability, N_s=Number of successful experiments and N=Total number of experiments

APPENDIX- B

Program

```
DEF Vinay ( )
INI

PTP HOME                    Vel=100%  DEFAULT

PTP  P1   Vel =100%  PDAT1 Tool[7]:ymca Base [7]: nicebase
Loop
PTP  P2   CONT Vel =100%  PDAT2 Tool[7]:ymca Base [7]: nicebase
LIN  P3   Vel =2 m/s  CPDAT1 Tool[7]:ymca Base [7]: nicebase

LIN  P2   CONT Vel =2 m/s  CPDAT2 Tool[7]:ymca Base [7]: nicebase
PTP P1    CONT Vel =100%  PDAT4 Tool[7]:ymca Base [7]: nicebase
Endloop
PTP HOME                    Vel=100%  DEFAULT

END
```