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SIMULATION AND EXPERIMENTAL WORK OF KINEMATIC PROBLEMS FOR KUKA KR 5 SIXX R650 ARTICULATED ROBOT

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ABSTRACT

This paper studies an analytic solution for 6-DOF manipulator of a KUKA KR 5 SIXX R650 robotic arm using forward and inverse kinematics in a simple movement process. This paper proposes two points of movement in order to study three types of path motion used in the robotic arm. The three path motions are PTP (point-to-point), linear and circular. The motions are analyzed systemically using forward kinematics and inverse kinematics. The objective of forward kinematic analysis is to determine the cumulative effect of the entire set of joint variables. A simulation oriented analysis is obtained and comparison between simulation and experimental result is done. The result for both simulation and experimental works show close connection for the task. This robot is suitable to be applied to the teaching and training environment.

Keywords: Kinematics, Manipulator, Trajectory, Robotic Arm

1. INTRODUCTION

Nowadays, robotic arms are used in various applications and environment. Each of them has their own complexity and uniqueness in order to fulfill the task given. However, many advance technologies are severely restricted in commercial system due to limitation of the controller rather than the manipulator arms (Kay, 2005). In order to overcome this limitation there were several systems been develop for example vision based system (Haniff et al. 2011). A robotic manipulator is designed to perform a task in the 3-D space. The tool or end-effector is to follow a planned trajectory to manipulate objects or carry out the task in the workspace. This requires control of position of each link and joint of the manipulator to control both the position and orientation of the tool (Lombai et al. 2008).

In order to understand how to control the position of each link and joint of the manipulator, it is important to analyze the kinematic solution of the robot. There are two kinematic topics discuss in this paper that is forward and inverse kinematic. Forward kinematic is about finding position of any coordinates by referring to the given length of each link and angle of each joint while inverse kinematic is about finding angles of each joint needed to obtain the position based on given length of each link and the position (Xu D. et al. 2005).

In this paper the focus will be on the forward kinematics and inverse kinematics problem of a KUKA KR 5 SIXX R650 robotic arm. KUKA Robotics is a well-known Germany manufacturer of industrial robots for various industrial processes. The robotic arm comes with a teaching pendant that has a display and an integrated mouse where manipulator is move or positions are create, edit and save. The latest teaching pendant uses the Windows XP operating system. The KR 5 SIXX R650 is a 6-axes robotic arm weighting 28kg with the payload up to 5kg (KUKA). This paper will focus specifically on the use of this type of robotic arm in a simple two point's movement process.

2. METHODOLOGY

2.1 Kinematic Theory and Analysis

In order to analyze the kinematic of arm robot, it is important to identify the coordinate frames. The z_i axis for all joints will follow the direction of rotation and the right-handed rule is use to identify the rotation (Diaz et al. 2010). Referring to Figure 1, at joint 1, z_0 is representing the first joint going upwards as it is a revolute joint. Then the direction of x_0 is chosen to be parallel with the reference frame of x-axis. Next z_1 is assigned at joint 2 and since z_0 and z_1 are intersecting, x_1 will be assigned as common normal. At joint 3, z_2 will have same direction as z_1 and x_2 will be common normal between z_1 and z_2. Direction of z_3

and z_5 is the same because both representing the same frame. So the direction of x_3, x_4 and x_5 is the same because in the direction of the common normal between z_2, z_3, z_4 and z_5. z_4 represent the motions of joint 5 and z_6 represent the motions of the end effectors. The coordinate frames that have been assigned will be the reference to fill the Table 1.

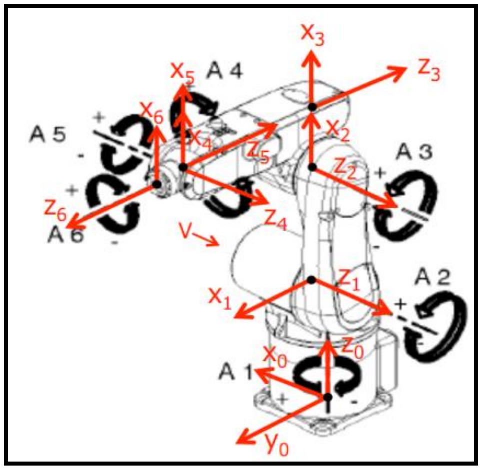


Figure 1 Joints of KUKA KR 5 SIXX R650

Table 1 Denavit-Hartenberg Parameters of All Links and Joints

Axis	*αi*	*di*	*ai*	*Θi*
1	-90º	335mm	75mm	Θ_1
2	0	0	270mm	Θ_2
3	90º	0	90mm	Θ_3
4	180º	295mm	0	Θ_4
5	-90º	0	0	Θ_5
6	180º	80mm	0	Θ_6

Calculating the position and orientation of the end-effector in terms of the joint variables is called as forward kinematics. In order to have forward kinematics for a robot mechanism in a systematic manner, one should use a suitable kinematics model. Denavit-Hartenberg method that uses four parameters is the most common method for describing the robot kinematics (Gan et al. 2010). This method is used for systematically establishing a coordinate system to each link of an articulated robot. The standard 4x4 homogeneous coordinate transformation matrix can be use to represent the transformation between adjacent coordinate frames when the coordinate frames are assigned (Verma et al. 2010). Frame [i-1] and frame should be consider [i] in order to find the transformation matrix relating two frames attached to the adjacent links. The transformations of frame [i-1] to frame [i] consists of four basic transformations.

1. A rotation about *zi-1* axis by an angle *θi*;
2. Translations along *zi-1* axis by distance *di*;
3. Translation by distance *ai* along *xi* axis and
4. Rotation by an angle *αi* about *xi* axis

The transformations between each two successive joints can be written by simply substituting the parameters from the parameters table into the H matrix.

$$H_{n+1} = \begin{bmatrix} \cos\theta_{n+1} & -\sin\theta_{n+1}\cos\alpha_{n+1} & \sin\theta_{n+1}\sin\alpha_{n+1} & a_{n+1}\cos\theta_{n+1} \\ \sin\theta_{n+1} & \cos\theta_{n+1}\cos\alpha_{n+1} & -\cos\theta_{n+1}\sin\alpha_{n+1} & a_{n+1}\sin\theta_{n+1} \\ 0 & \sin\alpha_{n+1} & \cos\alpha_{n+1} & d_{n+1} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

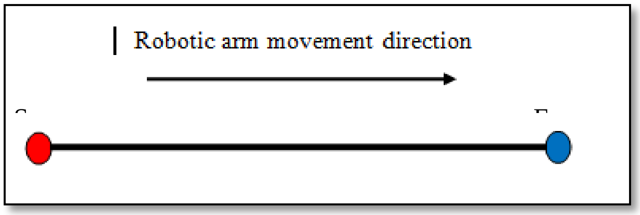
Inverse kinematic can be difficult to solve due to many possible solutions. There are many different joints configuration that could lead to the same endpoint. Several techniques can be use to solve the inverse kinematics. The techniques are Analytic Method which using Cosine Law and Jacobian Method. This paper will use Jacobian Method because it have been used to find the exact angle of each joint in order to reach the target (Herman et al. 2006). After considering the Jacobian method through the theoretical calculation based, the analysis which is using the Matlab RVC toolbox was done. To find the inverse kinematic in Matlab, the function that had been used is *r = k650.ikine(T)*.

2.2. Simulation Works

The simulation is using special robotic toolbox in MATLAB known as RVC toolbox. This Toolbox provides many functions that are useful for study and conducting a simulation of robotic arm. This Toolbox is based on a very general method of representing the kinematics and dynamics of serial-link manipulators. Robot model can be created by the user for any serial-link manipulator and a number of examples are provided for well know robots such as the Puma 560. In order to conduct a simulation, a model robot for KUKA KR5 SIXX R650 is created by referring the D-H parameters for this robot as shown in Table 1.

2.3. Experimental Works

The experimental on KUKA is done by developing the outline of the motion before proceed with the programming. The programming is created in Expert Mode. For PTP (point-to-point) and linear motion, the method to programming the robot is the same where only two points required (start point and end point) to create a path. While circular motion, it needs three points (start point, middle point and end point) to be insert as the reference to the robot.



Fiq. 2 Linear movement

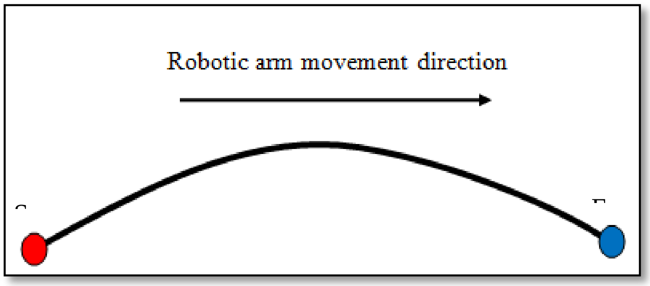


Fig. 3 PTP movement

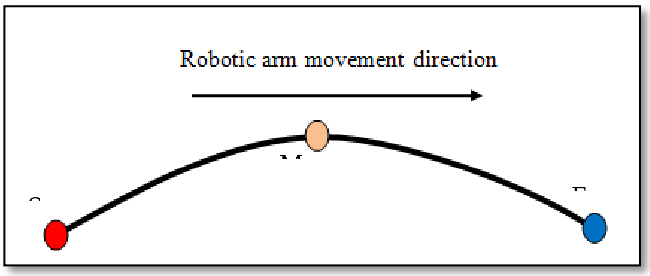


Fig. 4 Circular movement

3. RESULTS AND DISCUSSION

3.1 Simulation Results

The data from the changing angle on the joint will be simulated using Matlab RVC toolbox. This is to ensure every joint will produce accurate movement and the required end point. Fig. 5 describes the output of the simulation for start point of the robotic arm located at coordinate [0.492 0.147 0.229]. While Fig. 6 shows the endpoint for the robotic arm movement located at coordinate [0.498 -0.124 0.229]. All measurements are in meter.

3.2 Experimental Results

Fig. 7 describes the result of the experimental for start point of the robotic arm located at coordinate [482.35 134.38 230.02]. While Fig. 8 shows the experimental axis angle for start position. Fig. 9 describe the end position for the robotic arm movement located at coordinate [482.05 -159.34 230.05]. All measurements are in mm. Based on the results obtain, there are slightly different value for robot coordinates between simulation and experimental results. However this will not be an issue because both works are conducted separately. So it is common to have slight different. All three motion path (PTP, linear and circular) shows the same value for start point and endpoint coordinates. In experimental works, the different for these three motion path can be seen through the robotic arm movement. However in simulation works the robotic arm model in Matlab unable to simulate any three path motions due to software constraint.

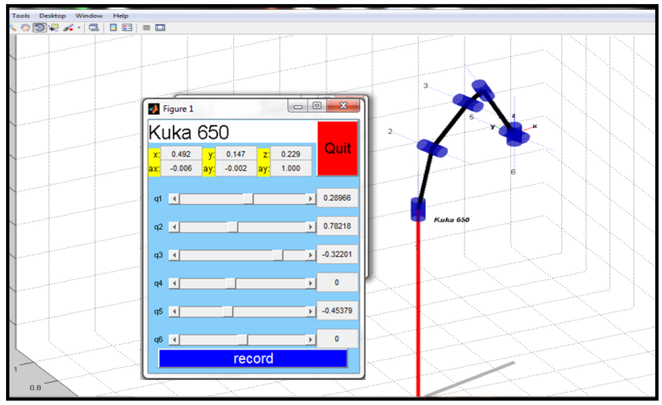


Fig. 5 Simulated movement for start position

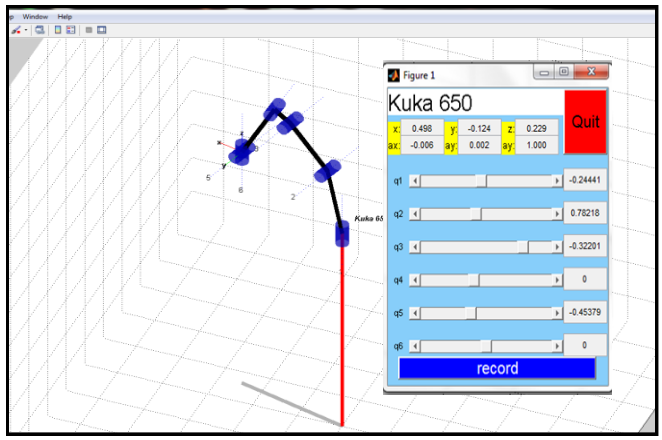


Fig. 6 Simulated movement for end position

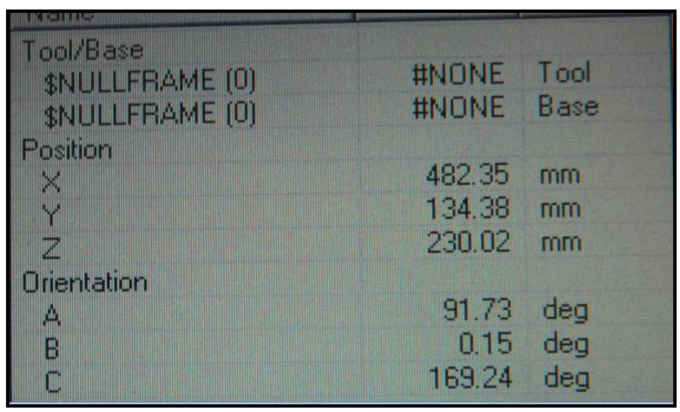


Fig. 7 Experimental robot coordinates for start position

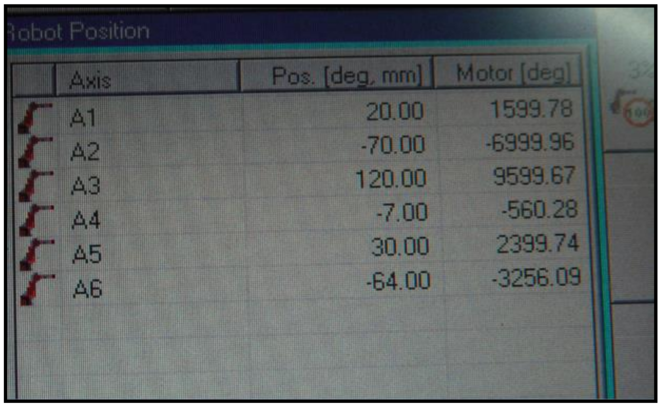


Fig. 8 Experimental axis angle for start position

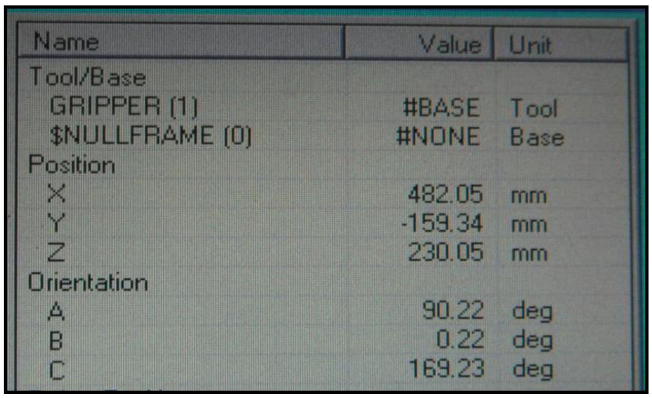


Fig. 9 Experimental robot coordinates for end position

4. CONCLUSION

The simulation results have shown that forward and inverse kinematics is successfully developed using KUKA KR5 SIXX R650 robotic arm model in MATLAB RVC toolbox. A general D-H representation of forward and inverse kinematic is obtained. Moreover, the experimental results also have verified the simulation work. Future work will focus on the optimization of energy utilization.

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