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# The Kinematics Analysis of Robotic Arm manipulators Cylindrical Robot RPP Type for FFF 3D Print using Scilab

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**Abstract** Robotic arm is a popular machine in industrial and has vast application. The FFF 3D Print are technology that has become more popular these day. This paper analyze the use of Cylindrical Robot RPP type robotic arm manipulator as 3D printer based on kinematics. First establishes reference frames by using D-H method and solves kinematic problems of robotic arm manipulator Cylindrical Robot type for FFF 3d Print. Finally, using the open software Scilab simulate the kinematics characteristics of the robotic arm for FFF 3d Print.

Keywords: Kinematics, Scilab, Simulation, Cylindrical robot, Mechanical Structure

## 1. Introduction

A basic requisite for robotic arm analysis is to determine the preference and positioning of objects in some domain. The object can assumed as a rigid body. So a robot arm can also assumed as a rigid objects connected from base to some device. The movement of a robot arm can be described as preference and positioning in a coordinate system. The most used is Cartesian coordinate, with perpendicular XYZ axes [2].

Robotic arm manipulator configurations can be classified into four types, including Articulated Robot (RRR), Spherical Robot (RRP), SCARA Robot (RRP), Cylindrical Robot (RPP), Cartesian Robot (PPP). Each type has advantages and disadvantages depending on the application[3].

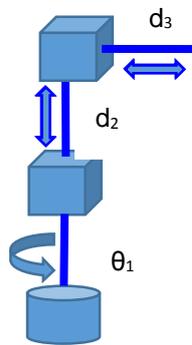
Additive manufacturing, well known as 3D printing, is an innovative manufacturing practical application that will play an important function in the manufacturing. Industrial-grade 3D printers are more and more used to produce functional parts for important systems[4]. Fuse deposition modelling (FFF) is one of type of Additive Manufacturing technology, this type uses material extrusion process. Material is drawn into a nozzle, where it is heated and then deposited layer by layer. The nozzle can move horizontally or vertically depend on type and also the platform after each new layer is deposited. This type of technology able to fabricate prototypes, tooling and functional parts without geometrical complexity limitations[5].



This paper firstly studies the robotic Arm Manipulators structure as 3D printer, and set up a kind of simplified configuration framework. Then establish the kinematics model and design the mode of motion. Finally, we using Scilab to simulate and analysis the kinematics characteristics of the robot.

## 2. Method

The robotic arm manipulator cylindrical type has three linkages, and are three joints, the first joint is revolute and produces a rotation about the base, while the second and third joints are prismatic. The Cylindrical arm has cylindrical shape workspace and often used in material transfer tasks, therefore this paper analysis the kinematic and studies possibilities movement for 3D printer application. Figure 1. shows a diagram of cylindrical arm.



**Figure 1.** The Cylindrical Robot RPP

### 2.1 Reference frame

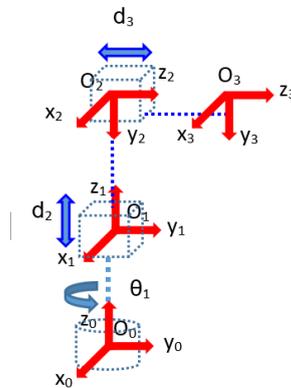
Measurement of the position and motion relationship between every linkage, a system of coordinate must be determine on every linkage. The position and motion of actuator in body coordinate system is built by the consideration of relations between every coordinate system. There are several procedures in determining reference frame base on the D-H convention[7]:

- Step one, build the first coordinate system ( $X_0, Y_0, Z_0$ ); this original point as the initial position of the robotic arm base centroid. This step can help us to get the other location parameters of the reference point in the space.
- Step two, Establish the base frame. Set the origin anywhere on the  $z_0$ -axis. The  $x_0$  and  $y_0$  axes are chosen conveniently to form a right hand frame.
- Step three, Locate the origin  $o_i$ , where the common normal to  $z_i$  and  $z_{i-1}$  intersect  $z_i$ .
- Step four, Establish  $x_i$  along the common normal between  $z_{i-1}$  and  $z_i$  through  $o_i$ .
- Step five, Establish  $y_i$  to complete a right hand frame.
- Step six, Establish end effector frame  $o_n x_n y_n z_n$ .
- Step seven, Create a table of link parameter  $a_i, d_i, \alpha_i, \theta_i$
- Step eight, Form the homogeneous transformation matrices  $A_i$ .
- Step nine, Form  $T_n^o = A_1 \dots A_n$

The coordinate system for each linkage is shown in Figure2.

The coordinate systems of linkage show as follows: The placement of  $O_0$  along  $z_0$  as well as the directon of the  $x_0$  axis are arbitrary. The axis  $x_0$  is chosen normal to the page and then the  $x_1$  axis is normal to the page when  $\theta_1 = 0$ . The z-axis between  $z_1$  and  $z_2$  is intersect and the  $o_2$  is placed at the

intersection. The orientation of  $x_2$  is chosen parallel with  $x_1$ , the effect is  $\theta_2$  zero. The last, third frame, chosen at the end of link 3 as Figure 2 shown.



**Figure 2.** The reference frames of cylindrical robot type

The link parameters can be summarized based on right-handed coordinate system into following list[8]:

$a_i$  = distance along  $x_i$  from  $o_i$  to the intersection of the  $x_i$  and  $z_{i-1}$  axes.

$d_i$  = distance along  $z_{i-1}$  from  $o_{i-1}$  to the intersection of the  $x_i$  and  $z_{i-1}$  axes.  $d_i$  is variable if joint  $i$  is prismatic.

$\alpha_i$  = the angle between  $z_{i-1}$  and  $z_i$  measured about  $x_i$

$\theta_i$  = the angle between  $x_{i-1}$  and  $x_i$  measured about  $z_{i-1}$ .  $\theta_i$  is variable if joint  $i$  is revolute.

### 2.2 Forward kinematics

All linkages can be represented using four parameters introduced before as a coordinate transformation of coordinate system, and it is need to be systematic to analyze of the frame. The convention in robotic implementation for selecting frames of reference is the Denavit-Hartenberg convention (D-H convention). This convention arranged the transformation each linkage as shown below[7]:

$$\begin{aligned}
 A_i &= Rot_{z, \theta_i} Trans_{z, d_i} Trans_{x, a_i} Rot_{x, \alpha_i} \\
 &= \begin{bmatrix} \cos\theta_i & -\sin\theta_i & 0 & 0 \\ \sin\theta_i & \cos\theta_i & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & a_i \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\alpha_i & -\sin\alpha_i & 0 \\ 0 & \sin\alpha_i & \cos\alpha_i & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \\
 &= \begin{bmatrix} \cos\theta_i & -\sin\theta_i \cos\alpha_i & \sin\theta_i \sin\alpha_i & \alpha_i \cos\theta_i \\ \sin\theta_i & \cos\theta_i \cos\alpha_i & -\cos\theta_i \sin\alpha_i & \alpha_i \sin\theta_i \\ 0 & \sin\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}
 \end{aligned}$$

The values of these four parameters before, can summarize based on the D-H coordinate systems which we have established. The Table 1 is all the value of parameters. The value of  $a$  is the distance of linkage between two joint.

Table 1. Link Parameters for 3-link cylindrical manipulator

Link	$a_i$ (mm)	$\alpha_i$ ( $^\circ$ )	$d_i$ (mm)	$\theta_i$ ( $^\circ$ )
1	0	0	$d_1$	$\theta_1^*$
2	0	-90	$d_2^*$	0
3	0	0	$d_3^*$	0

\*variable

The entire joints of the robot is driven by motor, the motor is rotating and directly produce rotating angle ( $\theta_i$ ) and also convert to axial movement ( $d_2, d_3$ ). From Table 1 we know that the parameter  $\theta_1, d_2$ , and  $d_3$  is the variable when the reference frames of the robot have been established. The homogeneous transformation between every two coordinate system is analyzed. If we give values to each parameters, the robot will move and will go to the certain position.

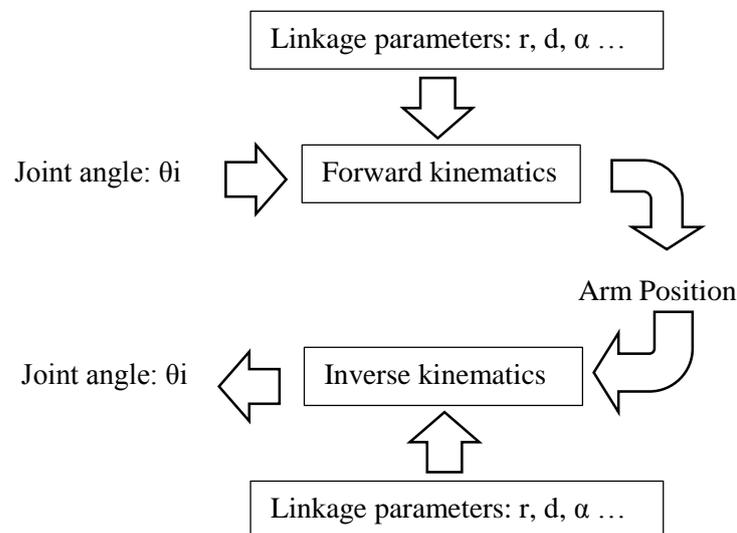
The link parameters are shown in the table, the corresponding A and T matrices shown below:

$$A_1 = \begin{bmatrix} c_1 & -s_1 & 0 & 0 \\ s_1 & c_1 & 0 & 0 \\ 0 & 0 & 1 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad A_2 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad A_3 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_3^0 = A_1 A_2 A_3 = \begin{bmatrix} c_1 & 0 & -s_1 & -s_1 d_3 \\ s_1 & 0 & c_1 & c_1 d_3 \\ 0 & -1 & 0 & d_1 + d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

### 2.3 Inverse Kinematics

The study of forward kinematics problem can be used to resolve whether the motion of robot fit with the condition, moreover the study also be used as construct the study of inverse kinematics. The flow chart process of forward kinematics and inverse kinematic of robotic arm is show as below [10, 11].



**Figure 3.** The flow chart process for forward and inverse kinematics

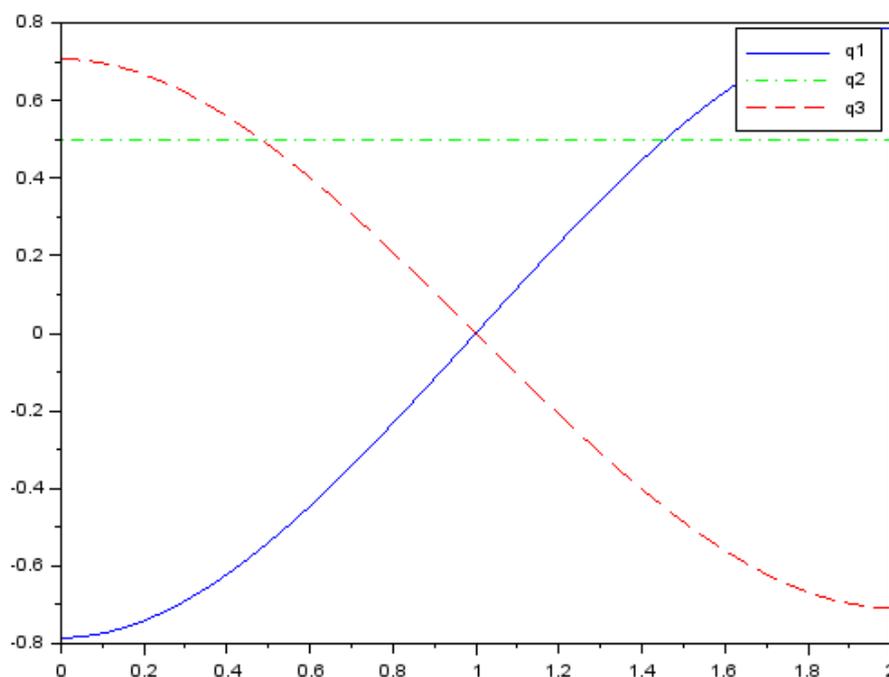
The study of inverse kinematics problem can find out whether the robot can achieve the desired movement and position or not. When the robot's position control and trajectory planning is executed or the arm position and orientation has been declare, and then the information used to determine the joint rotation angles ( $\theta$ ) to drive the motor of each joint to fit the position and orientation demanded of arm. Therefore, inverse kinematics study is to measure the parameter of  $\theta$ , and this is important for robot

motion control system. The measurement of  $\theta$  are back measurement operations of the equations mentioned before

### 3. Discussion

#### 3.1 The trajectory planning design of Robotic Arm manipulators Cylindrical Robot RPP Type

The design of movement of robot, give an important influence on the trajectory of the joints and also to the kinetic characteristic of the robot. Moreover it also influence the continuity, stability, aesthetic and torque of the robot when operate. If the trajectory is generated as an array of joint position, it can command the feedback control directly. Trajectory in Cartesian space, on the other hand, must be converted to joint position by means of inverse kinematic equation[3]. As shown in Figures 4, the joint position from trajectory generated in joint space.



**Figure 4.** Joint position from trajectory generated in joint space

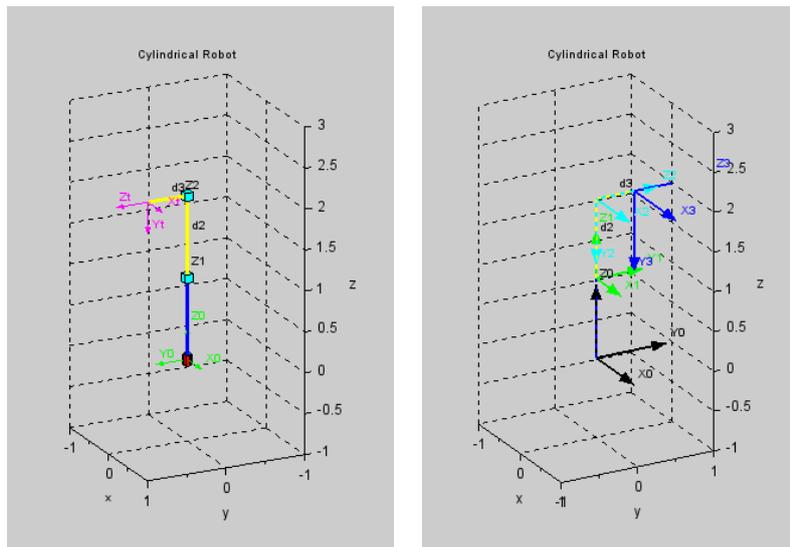
The movement of rotational joint and prismatic joints which based on the upper figures meets the laws as below: [9]

- When the robot operate, the rotational joint and prismatic joint have fixed phase relationship.
- When the robot swinging, the rotational joint and the prismatic joint has a synchronization motion.
- In the course of supporting, the rotational joint rotate steadily and the prismatic joint keep still.

#### 3.2 Simulation analysis and verification

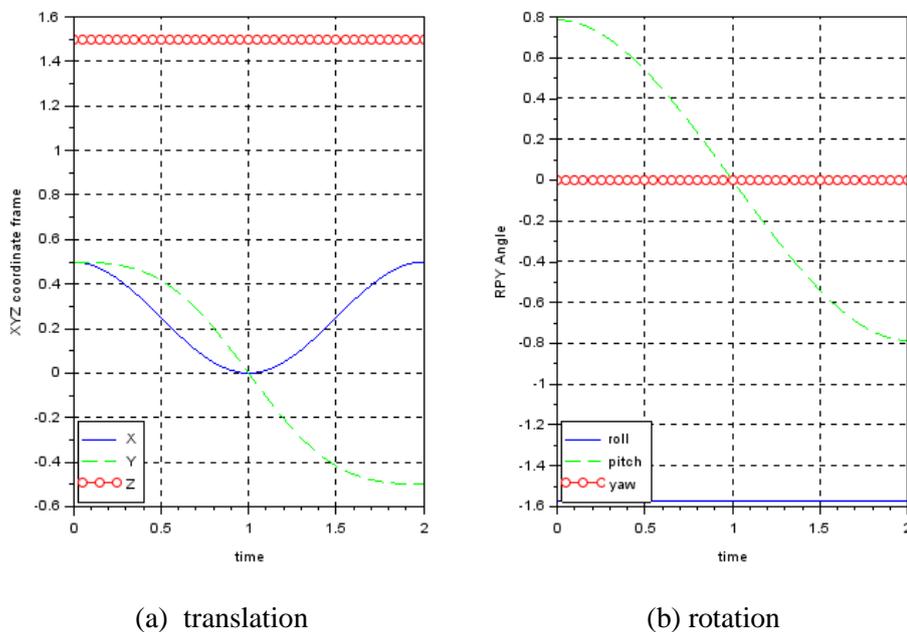
The Robotics Toolbox for Scilab (RTSX) [3] give amount of functions that are helpful in the field of robotics to study kinematics, dynamics and trajectory generation etc. It is propective for modeling and simulating robotic manipulators as well as for studying the results that obtained from experiments with real robots.

In this study, a simulation of trajectory of robotic arm has been done to verify the kinematic equations. Firstly, the 3-D model of Robotic Arm manipulators Cylindrical Robot RPP Type has been designed in Scilab, that is shown in Figure 5.



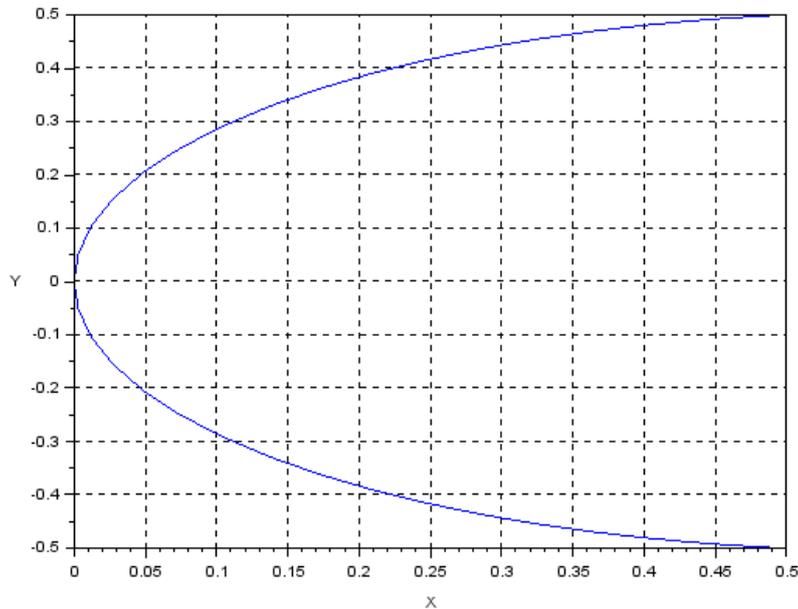
**Figure 5.** The 3D Model and Frame of Robotic Arm manipulators Cylindrical Robot RPP Type

Based on figure 5, there are no idea how the end-effector moves in Cartesian space. So we need compute forward kinematic from the joint position vector in RTSX toolbox of SCILAB. The result will plot and show translational parts and rotational parts.



**Figure 6.** Cartesian trajectory of robotic arm resulting from joint-space generator

In the X direction of figure 6 there is some deviation, this can be seen more clearly by plotting the path in XY plane in figure 7 as below.



**Figure 7.** End-effector path in XY plane from joint-space generator

From Figure 7 the motion is an arc instead of straight line. The data and curve of the simulation have been tested and verified the right of the equations in positive and negative kinematics questions which is deduced in forward.

#### 4. Conclusion

The simplified mechanical structure of Robotic Arm manipulators Cylindrical Robot RPP Type, analyzed the kinematics using D-H method. Based on the resulting trajectory, we can conclude that this robotic arm can be used as a 3D printer. The software Scilab with RTSX toolbox for kinematics simulation with SCILAB able to show the movement of robot, and also provides real-time analysis of the joint variables, which lays foundation for following-up motion control.

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