MTRN 4230 – Individual Research Report

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1. Describe what is the application you have selected and what is the robot you have found commercially available suitable for that application. Include the reasons you have selected this area of application and that robot, including safety, workspace, payload, and accuracy

This individual research report focuses on additive manufacturing technology, well known as 3D printing. It is a vital component for industry 4.0, the reasons conclude as following [1]:

- Speed: 3D printing technology makes the prototyping process faster, which enables the design, manufacture, and test a customized industrial component in a short time.
- Cost: 3D technology only requires 1 or 2 machines and fewer workers to fabricate one product. Also, the raw material is less wasted due to the 3D-printing production is built up from the bottom to top.
- Flexibility: 3D printing allows the manufacturer to customize and produce the industrial components with the nature of complex geometry. Meanwhile, it provides a possibility that multiple types of raw material could construct a single component in order to increase the particular characteristic, such as durability or stretchability.

The cylindrical manipulator (RPP) is a three-link manipulator with three joints. The first joint is revolute, making the base rotated about the z-axis, and the second and third joints are prismatic. The Seiko RT 3300/3200 is a typical cylindrical robot arm. It has been shown in Figure 1.

Figure 1 Seiko RT 3300 [2]

The reasons to select this type of robot arm as a researching object are listed as below [3]:

- An apparent reason is that its kinematic analysis is relatively straightforward.
- Another reason is that this body structure enables the manipulator to operate in a cylindrical space. The dimensions of the workspace can be constrained by the link motions in the horizontal and vertical directions. As such, the workspace of the cylindrical manipulator is under control so that the physical hazards could be avoided.
- Meanwhile, compared with the cartesian robot, the cylindrical robot is able to move faster between the required points, particularly for the situations that the two points are located on the same plane.

The performance of Seiko RT 3300 can be evaluated from these aspects:

- Safety: For all types of industrial robots, the potential hazards may be resulting from human errors, control errors, unauthorized access, mechanical failures, environmental sources, power systems, and improper installation. However, these dangers in the workplace are preventable if the worker is well trained, and robotic integration is fulfilled with the safety requirements [4]. Also, it is a fact that the cylindrical robots could be applied in the scenario of the assembly lines in order to operate the tasks, possibly causing the ergonomic injuries or accidents to the human health, such as over-reaching and repetitive motion [5].

- Workspace: The first joint produces a rotation, while the second and third joints produce the linear motions. The workspace of this cylindrical manipulator is a cylindrical-shaped envelope. The linear distances along links could modify the volume.

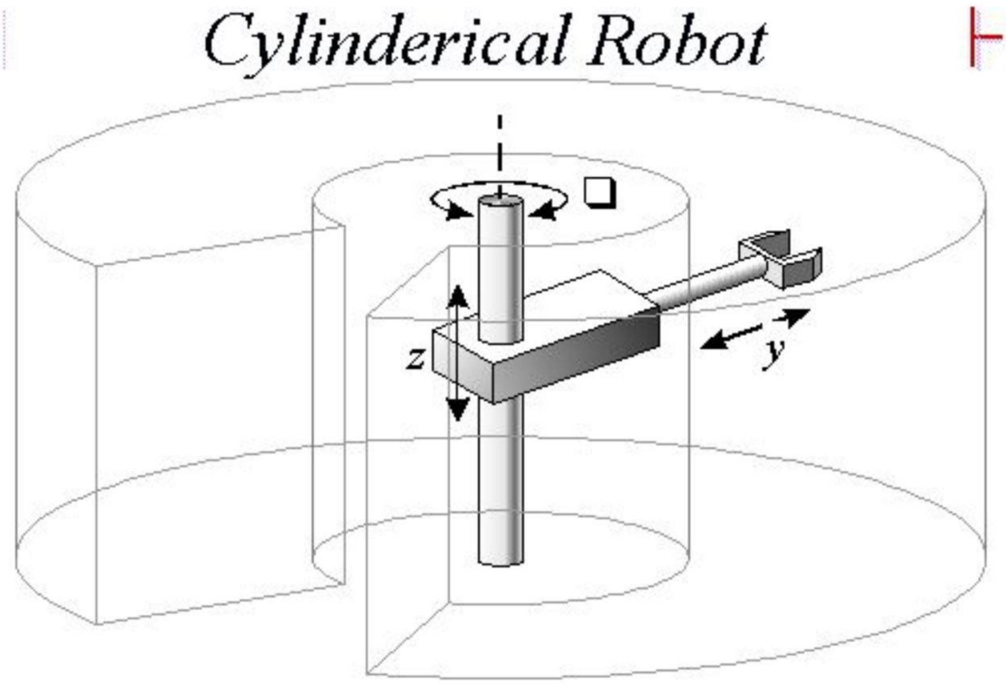


Figure 2 Workspace of Cylindrical Robot [3]

- Payload: This cylindrical manipulator is capable of carrying the objects weighted 5kg to 12kg in the standard model, and 2.5kg to 12kg in the 100mm shift model [2].

- Accuracy: The accuracy of this manipulator can be measured by examining how accurately the same position can be reached after multiple times. This robot arm remains highly accurate in the motions because its repeatability is approximately ± 0.025mm in X, Y-axis, and $\pm 0.03°$ in the Z-axis [2]

2. How the robot and application of robot you have selected is influenced or can be influenced by Industry 4.0

Essentially, industry 4.0 is a digital revolution, which will rapidly transform the fashion that business and manufacturing are conducted. Inside of this digital transformation, the prosperous industrial company will become the digital enterprises with organic products, along with the advanced data-based services. These digital enterprises will collaborate with customers and suppliers for constructing a new supply chain [6].

3D printing is known as an advanced manufacturing technology for fuse deposition modeling. It is used to produce the prototypes and functional components without geometrical complexity limitations. Besides, the data generated by customer software can be directly delivered to the 3D printers while prototyping.

Concerning this background, 3D printing technology is playing an essential role in this digital transformation of business and manufacturing. Meanwhile, it is acknowledged that the cylindrical manipulator is appropriately used to build the 3D printer [7]. Hence, the development of this robot arm will increase the adoption of 3D printers. As 3D printing expands, it will speed up the process of digitalization in the industry.

3. Research about tools and software in relation to that robot. It includes programming, simulators, and training tools

Programming: Scilab (https://www.scilab.org/software) running on Windows, Linux, or Mac OS, is open-source software for numerical computation. It can be utilized to program the joint motions of the cylindrical manipulator. This software is also able to implement numerical analysis, data visualization, algorithm development, and application deployment [8].

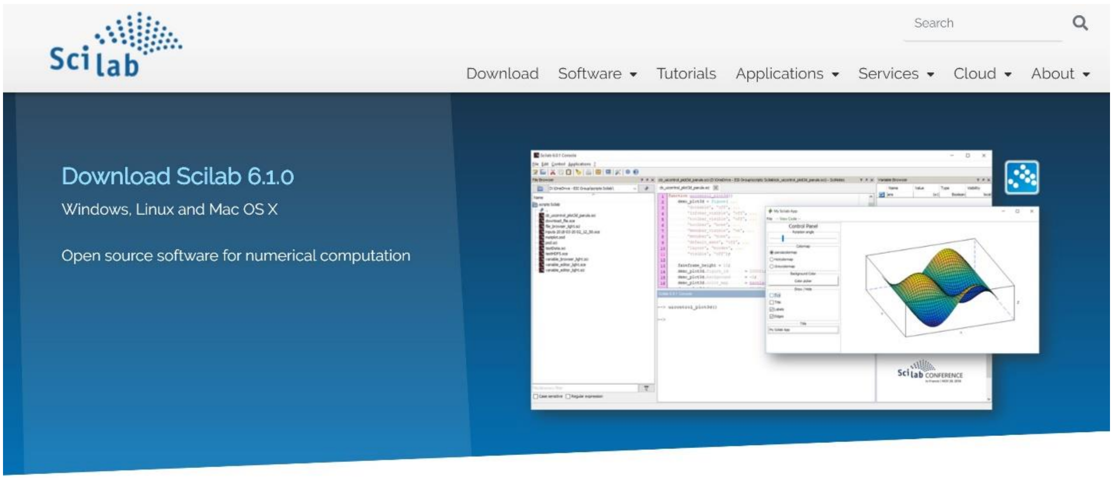


Figure 3 Website page of the Scilab software [8]

Simulation: The robot toolbox for Scilab (https://atoms.scilab.org/toolboxes/Robotics_Toolbox) could provide a set of functions that are used to study and simulate the kinematics, dynamics, and trajectory for the cylindrical manipulator. These functions are including creating a robotic model based on the D-H notation, determining the forward and inverse kinematic, and displaying a graphical schematic model of a robot arm with animation, etc. The robotics toolbox inspires this toolbox for MATLAB created by Peter Corke, but mainly for the Scilab software.

Robotics Toolbox

A toolbox for the simulation of robotic manipulators

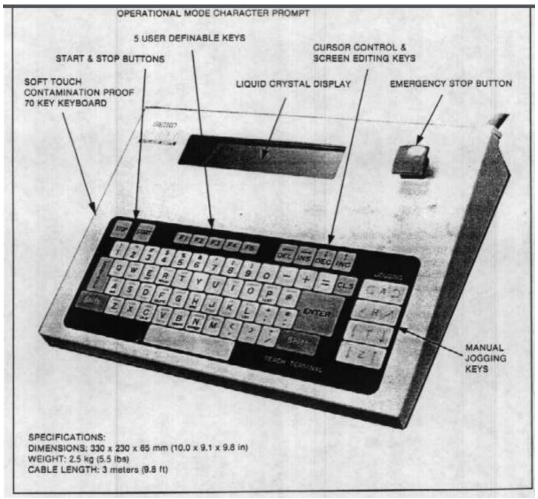
(2514 downloads for this version - 16492 downloads for all versions)

Details

Version	2.0.0
Author	Davide Cappucci and Corrado Guarino Lo Bianco
Owner Organization	University of Parma
Maintainer	Corrado Guarino Lo Bianco
Category	Modeling - Control Tools
License	GPL (3.0)
Creation Date	December 20, 2019
Source created on	Scilab 6.0.x
Binaries available on	Scilab 6.0.x: Linux 64-bit Windows 64-bit
Install command	`--> atomsInstall("Robotics_Toolbox")`

Figure 4 Website page of robotics toolbox on the Scilab [9]

Training tools: For the Seiko RT 3300, the Seiko pendant and Seiko D-TRAN Teach-terminal are external equipment for programming the robot. Also, these peripheral terminals are available to help the demonstrators to train the new users, with the Seiko RT 3200 manual expressing the initial start-up and operation of the robot unit.



3.7 BASIC OPERATIONS OF THE RT 3000 ROBOT

INITIAL START-UP & OPERATION OF THE UNIT

The remainder of this section describes the steps necessary to power up and operate the unit. Some easy introductory programs are given, but only to satisfy the natural curiosity of the operator. Please be sure to read the entire section on DARL very carefully before operating the unit!

The assumption is made that the unit has been unpacked and properly set-up as described previously in this section.

The power supply must have been measured and the voltage tap on the transformer must be properly set. Be sure to review Section 3.4 (3-Phase) or 3.5 (Single Phase) before attempting to power up the unit.

Information regarding day-to-day operation can be found at the end of this section.

The following subsections lay out a step-by-step procedure to power-up the robot unit and begin operation. These steps should be reviewed whenever there are difficulties in powering up the unit. Some subsections request a specific action and detail the expected system response. If these procedures are not successful, please contact your local distributor or SEIKO INSTRUMENTS U.S.A., Inc.

Figure 5 Training/Teaching tools for the cylindrical robot arm [2]

4. Develop forward and inverse kinematic of the robot in MATLAB

Based on the reference frame of this cylindrical manipulator type [7], the parameters of links can be represented in the D-H convention as below:

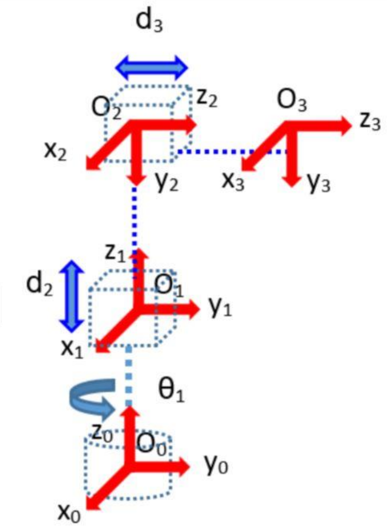


Table 1 DH parameters for cylindrical robot arm

Link	Angle (θ_i)	Offset (d_i)	length (a_i)	Twist (α_i)
1	θ_1	d1	0	0
2	0	d2	0	-90
3	0	d3	0	0

where the θ_1, d2 and d3 are variables in the kinematics matrix.

In accordance with these D-H parameters and the homogeneous transformation matrix, the forward kinematics can be obtained on MATLAB,

```
syms d1 d2 d3 theta1
T1 = [cos(theta1) -sin(theta1) 0 0;
      sin(theta1) cos(theta1) 0 0;
      0 0 1 d1;
      0 0 0 1]

T2 = [1 0 0 0;
      0 0 1 0;
      0 -1 0 d2;
      0 0 0 1]

T3 = [1 0 0 0;
      0 1 0 0;
      0 0 1 d3;
      0 0 0 1]

fKinMatrix = simplify(T1*T2*T3)
```

T1 =

$$\begin{pmatrix} \cos(\theta_1) & -\sin(\theta_1) & 0 & 0 \\ \sin(\theta_1) & \cos(\theta_1) & 0 & 0 \\ 0 & 0 & 1 & d_1 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

T2 =

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & d_2 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

T3 =

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_3 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

fKinMatrix =

$$\begin{pmatrix} \cos(\theta_1) & 0 & -\sin(\theta_1) & -d_3\sin(\theta_1) \\ \sin(\theta_1) & 0 & \cos(\theta_1) & d_3\cos(\theta_1) \\ 0 & -1 & 0 & d_1 + d_2 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Figure 6 Forward kinematics matrix for cylindrical robot arm

The "fKinMatrix" is available to express the homogeneous transformation between the base frame to the end-effector frame.

In order to determine the inverse kinematics matrix, some equations can be generated from the homogeneous transform and forward kinematics matrix,

$$X = -d_3 \sin(\theta_1)$$

$$Y = d_3 \cos(\theta_1)$$

$$Z = d_1 + d_2$$

where [X, Y, Z] is the location of the end effector in the 3D cartesian workspace.

Hence, the joint variables can be derived from the above equations,

$$\theta_1 = \operatorname{atan}\left(-\frac{X}{Y}\right)$$

$$d_2 = X^2 + Y^2 - d_1$$

$$d_3 = \sqrt{X^2 + Y^2}$$

In summary, the inverse kinematics matrix can be stated as,

$$\begin{bmatrix}\theta_1\\ d_2\\ d_3\end{bmatrix}=\begin{bmatrix}\operatorname{atan}\left(-\frac{X}{Y}\right)\\ X^2+Y^2-d_1\\ \sqrt{X^2+Y^2}\end{bmatrix}$$

The MATLAB codes for calculating the inverse kinematics matrix are shown below,

```
syms x y z
theta1 = atan(-x/y)
d2 = x^2 +y^2 -d1
d3 = sqrt(x^2+y^2)
iKinMatrix = [theta1;d2;d3]
```

theta1 =

$$-\operatorname{atan}\left(\frac{x}{y}\right)$$

d2 = $x^2+y^2-d_1$

d3 = $\sqrt{x^2+y^2}$

iKinMatrix =

$$\begin{pmatrix}-\operatorname{atan}\left(\frac{x}{y}\right)\\ x^2+y^2-d_1\\ \sqrt{x^2+y^2}\end{pmatrix}$$

Figure 7 Inverse kinematics matrix for cylindrical robot arm

5. Simulate the robot for both forward and inverse kinematic as a demo in MATLAB, record a video

The simulation of the cylindrical manipulator is implemented by MATLAB programming as following, and the serial-link robot class could automatically form the forward and inverse kinematics based on the mechanism of D-H parameters. The video to display the animation is attached to this document.

```
% Author： Runkai Zhao
% zID: z5146927
% Time: 24/8/2020

q0 = [0 0 0];
qf = [pi, 5, 5];
T = 0:0.05:6;
[q,qd,qdd] = jtraj(q0,qf,T);

L(1) = Link('revolute', 'a', 0, 'alpha', 0, 'd', 0.5);
L(2) = Link('prismatic', 'a', 0, 'alpha', -pi/2, 'theta', 0);
L(3) = Link('prismatic', 'a', 0, 'alpha', 0, 'theta', 0);
cylRobot = SerialLink(L, 'name', 'RPP');

t = cylRobot.fkine(q); % use the forward kinematics to get locations of end-effect
q = cylRobot.ikine(t, 'mask', [1 1 1 0 0 0]); % use inverse kinematics to figure out the joint angles and distances

cylRobot.plotopt = {'workspace', [-1 1 -1 1 -1/5 1]*8,'tilesize',1};
figure(1); title("cylindrical manipulator");
cylRobot.plot(q); % animate the robot arm based on the joint angles and distances.
```

Figure 8 Simulation for cylindrical robot arm

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