INTRODUCTION TO ROBOTICS WITH iARM

SAURABH PALAN

NOTE: THIS BOOK USES THE REFERENCE TO iARM, 4-AXIS ROBOTIC ARM DEVELOPED BY ME FOR TRI TECHNOSOLUTIONS PVT LTD

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INTRODUCTION TO ROBOTICS

Robotics is a science of modern technology of general purpose of programmable machine systems. Robots perform a flexible, but restricted, number of operations in computer-aided manufacturing processes. These systems minimally contain a computer or a programmable device to control operations and effecters, devices that perform the desired work. The next paragraph represents the vision or general definition of robots according to the scientific knowledge and technology of that era.

General definition for Robot

"A re-programmable, multifunctional mechanical manipulator designed to move material, parts, tools, or specialized devices through various programmed motions for the performance of a variety of tasks." (Robot Institute of America, 1979).

Robotics is a science that combines a range of fields like Mechanical Engineering, Electrical Engineering, and Computer Science. Robotics is ideal for students because it exposes them to hands-on applications of math, science, and engineering concepts. In addition, robotics motivates potential scientists and engineers to understand how things work and encourages them to use their imagination to create new technologies and improve old technologies.

A new perception and vision of the robot representation includes the following characteristics:

Robot Terminology

Workspace envelope describes how the robot is constrained by its mechanical systems configuration. Each joint of a robot has a limit of motion range. A workspace envelope of a robot is defined as all the points in the surrounding space that can be reached by the robot. Clear understanding of the workspace envelope of a robot to be used is important because all interaction with other machines, parts, and processes only takes place within this volume of space.

Joints provide more versatility to the robot itself and are not just a point that connects two links or parts that can flex, rotate, revolve and translate. Joints play a very crucial role in the ability of the robot to move in different directions providing more degree of freedom.

- Prismatic joints, these are the second most employed joint and are also known as sliding as well as linear joints. (Fig a)
• **Revolute joints**, these are the most utilized joint and it permits only angular motion between links. (Fig b)

• **Cylindrical joints**, these are very rare and are use in some equipment like Parallel Robots or Flying simulator Mechanism. (Fig c and Fig d)

• **Spherical joints**, these are the third most utilized joint and just slide causing a revolving movement. (Fig e)

• **Screw joints**, these just follow the thread of the axis in spiral to move along the axis.

**Degrees of freedom**: DOF can be defined as the direction in which a robot moves when a joint is actuated. Each joint usually represent one degree of freedom. Most of the robots used today use five or six degrees of freedom. But this depends on the robot application, for example a pick-and-place application need only three axes specified when a welding robot requires five or six degrees of freedom.
ROBOT MANIPULATORS

Over the years robot manufacturers have developed many types of robots of differing configurations and mechanical design, to give a variety of spatial arrangements and working volumes. These have evolved into six common types of system:

**Cartesian robot** it is form by 3 prismatic joints, whose axes are coincident with the X, Y and Z planes. These robots move in three directions, in translation, at right angles to each other.

![Cartesian Robot Diagram](image)

**Applications:**
- pick and place work
- assembly operations
- handling machine tools
- arc welding

**Advantages:**
- Ability to do straight line insertions into furnaces.
- Easy computation and programming.
- Most rigid structure for given length.

**Disadvantages:**
- Requires large operating volume.
- Exposed guiding surfaces require covering in corrosive or dusty environments.
- can only reach front of itself
- axes hard to seal
Cylindrical robot is able to rotate along his main axes forming a cylindrical shape. The robot arm is attached to the slide so that it can be moved radially with respect to the column.

Applications:
- handling at die-casting machines
- assembly operations
- handling machine tools
- spot welding

Advantages:
- can reach all around itself
- rotational axis easy to seal
- relatively easy programming
- rigid enough to handle heavy loads through large working space
- good access into cavities and machine openings

Disadvantages:
- can't reach above itself
- linear axes is hard to seal
- won’t reach around obstacles
- exposed drives are difficult to cover from dust and liquids
**Spherical robot** is able to rotate in two different directions along his main axes and the third joint moves in translation forming a hemisphere or polar coordinate system. It used for a small number of vertical actions and is adequate for loading and unloading of a punch.

Applications:
- handling at die casting
- handling machine tools
- arc/spot welding

**Advantages:**
- Large working envelope.
- Two rotary drives are easily sealed against liquids/dust.

**Disadvantages:**
- Complex coordinates more difficult to visualize, control, and program.
- Exposed linear drive.
- Low accuracy.
**SCARA robot** which stands for Selective Compliance Assembly Robot Arm it is built with 2 parallel rotary joints to provide compliance in a plane. The robots work in the XY-plane and have Z-motion and a rotation of the gripper for assembly.

Applications:

- pick and place work
- assembly operations

**Advantages:**

- High speed.
- Height axis is rigid
- Large work area for floor space
- Moderately easy to program.

**Disadvantages:**

- Limited applications.
- 2 ways to reach point
- Difficult to program off-line
- Highly complex arm
Articulated robots are mechanic manipulator that looks like an arm with at least three rotary joints. They are used in welding and painting; gantry and conveyor systems move parts in factories.

Applications:
- assembly operations
- welding
- weld sealing
- spray painting
- handling at die casting or fettling machines

Advantages:
- all rotary joints allows for maximum flexibility
- Any point in total volume can be reached.
- All joints can be sealed from the environment.

Disadvantages:
- Extremely difficult to visualize, control, and program.
- Restricted volume coverage.
- low accuracy
1. **Number of Axes**

Each robotic manipulator has number of axes about which its links rotate or along which its links translates.

<table>
<thead>
<tr>
<th>Axes</th>
<th>Type</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-3</td>
<td>Major</td>
<td>Position the wrist</td>
</tr>
<tr>
<td>4-6</td>
<td>Minor</td>
<td>Orient the tool</td>
</tr>
<tr>
<td>7-n</td>
<td>Redundant</td>
<td>Avoid Obstacles</td>
</tr>
</tbody>
</table>

The Major axes determine the shape of work envelope. The Minor axes determine the arbitrary orientation of the tool in 3D space. The Mechanism for activating the tool is not regarded as independent axis, because it does not contribute to either the position or the orientation of the tool. The Redundant axes are useful for reaching around obstacles in the workspace or avoiding undesirable geometrical configurations of the manipulator.

2. **Tool Orientation**

*Position*: The translational (straight-line) location of something.

*Orientation*: The rotational (angle) location of something. A robot’s orientation is measured by *roll*, *pitch*, and *yaw* angles.

<table>
<thead>
<tr>
<th>Operation</th>
<th>Description</th>
<th>Axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Yaw</td>
<td>f₁</td>
</tr>
<tr>
<td>2</td>
<td>Pitch</td>
<td>f₂</td>
</tr>
<tr>
<td>3</td>
<td>Roll</td>
<td>f₃</td>
</tr>
</tbody>
</table>

To specify the tool orientation, a mobile coordinate frame M= \{m₁, m², m³\} is attached to the tool and moves with the tool. Initially,
the mobile tool frame M starts out coincident with a fixed wrist coordinate frame \( F = \{ f_1, f_2, f_3 \} \)

### 3. Reach and Stroke

- The **horizontal reach** is the maximum radial distance the tool can be positioned from the vertical axis about which the robot rotates.
- The **horizontal stroke** is defined as the total radial distance the wrist can travel.
- The **vertical reach** is the maximum elevation above the work surface that the tool can reach.
- The **vertical stroke** is defined as the total vertical distance the tool can reach.

\[ \text{Stroke} \leq \text{Reach} \]

### 4. Repeatability, Accuracy & Precision

- **Accuracy**: The measure of the ability of a robot to place the tool tip at an arbitrarily prescribed location in the work envelope.

- **Repeatability**: The measure of the ability of the robot to position the tool tip in the same place repeatedly.

- **Precision**: The measure of the spatial resolution with which the tool can be positioned within the work envelope.

### 5. Load Bearing Capacity

The maximum weight-carrying capacity of the robot.
**What is iARM?**

The iArm is a typical robotic arm model which is usually used to simulate actions of human arm and is a basic platform for the study purpose of various robotic arms, and can be applied in many fields such as research, education, entertainment etc. and it is also a good tool to expand your view and enhance your ability. Through the software’s control, the iARM will be able to simulate various operations, and that will make the Robotics theory visualizes more interesting.

**Features of iARM.**

1. An efficient Lab tool for learning of Kinematic Analysis of Robot Manipulator.

2. Direct Kinematics analysis through easy to use GUI and position control through USB port.

3. Task Planning through multiple position selection option.

4. Complete 3D workspace analysis and real time simulation through software.

5. Parallel Gripper for better and firm gripping.

6. Precise position control using RC Servo Motors.
iARM Specifications

1. iARM is a 4 DOF Articulated Robotic Manipulator.

2. Three Major axes and one minor axes - Major axes are Base, Shoulder and Elbow.
   The minor axis is Tool Pitch.
3. All the joints of iARM are Revolute joints.

4. Horizontal Reach: 400mm

5. Vertical Reach: 290mm

6. Load Capacity: 100gms

7. Gripper Mechanism: Parallelogram Gripper
KINEMATICS

KINEMATICS is the analytical study of the geometry of motion of a mechanism:

- with respect to a fixed reference co-ordinate system,
- Without regard to the forces or moments that cause the motion.

In order to control and program a robot we must have knowledge of both its spatial arrangement and a means of reference to the environment.

TWO FRAMES KINEMATIC RELATIONSHIP

There is a kinematic relationship between two frames, basically a translation and a rotation. This relationship is represented by a $4 \times 4$ homogeneous transformation matrix.

Fundamental Rotation

A fixed frame ‘f’ is attached to the base of the robot, where as a mobile co-ordinate frame is attached to the tool.

The Rotation is represented by a $3 \times 3$ matrix

$$ R_k(\theta) = \begin{bmatrix}
  f^1.m^1 & f^1.m^2 & f^1.m^3 \\
  f^2.m^1 & f^2.m^2 & f^2.m^3 \\
  f^3.m^1 & f^3.m^2 & f^3.m^3 \\
\end{bmatrix} $$
Rotation about 1\textsuperscript{st} axis

\[ R_1(\theta) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \theta & -\sin \theta \\ 0 & \sin \theta & \cos \theta \end{bmatrix} \]

Rotation about 2\textsuperscript{nd} axis

\[ R_2(\theta) = \begin{bmatrix} \cos \theta & 0 & \sin \theta \\ 0 & 1 & 0 \\ -\sin \theta & 0 & \cos \theta \end{bmatrix} \]

Rotation about 3\textsuperscript{rd} axis

\[ R_3(\theta) = \begin{bmatrix} \cos \theta & -\sin \theta & 0 \\ \sin \theta & \cos \theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \]

**Composite Rotation**

- Fundamental Rotations are represented by a Matrix. But in Matrix multiplication \([A][B] \neq [B][A]\).
- Hence the order in which fundamental rotations are performed is important and makes difference in the resulting Composite Rotations.
- Also the rotations can be performed about Fixed coordinate frame or Mobile Coordinate frame

**YAW-PITCH-ROLL Composite Rotation Matrix:**

\[
YPR(\theta)_{\text{fixed}} = \text{RPY}(\theta)_{\text{mobile}} = R_3(\theta_3)R_2(\theta_2)R_1(\theta_1) = \\
\begin{bmatrix}
C\theta_3 & -S\theta_3 & 0 \\
S\theta_3 & C\theta_3 & 0 \\
0 & 0 & 1 \\
\end{bmatrix}
\begin{bmatrix}
C\theta_2 & 0 & S\theta_2 \\
0 & 1 & 0 \\
-S\theta_2 & 0 & C\theta_2 \\
\end{bmatrix}
\begin{bmatrix}
1 & 0 & 0 \\
0 & C\theta_1 & -S\theta_1 \\
0 & S\theta_1 & C\theta_1 \\
\end{bmatrix}
\]
Homogeneous Transformation Matrix

A homogeneous transformation matrix represents both a rotation and a translation of the mobile frame with respect to the fixed frame.

\[
T = \begin{bmatrix}
R & P \\
\eta & \sigma
\end{bmatrix}
\]

- The origin of the translated coordinate frame is not same as the origin of the original coordinate frame due to translation in the 3D space.
- Hence it is not possible to represent a translation with 3x3 matrix.
- A homogeneous transformation matrix represents both rotation and translation of mobile coordinate frame w.r.t fixed coordinate frame

3x3 rotation matrix \[ r_1 \quad r_2 \quad r_3 \quad \Delta x \]

3x1 translation \[ \Delta y \quad \Delta z \]

1x3 perspective \[ 0 \quad 0 \quad 0 \quad 1 \quad \text{global scale} \]

- A sequence of individual rotations and translations can be represented as a product of fundamental homogeneous transformation matrix \( T \). But the order as well as the axis of rotation (F or M) is important, since \( [A] [B] \neq [B] [A] \) in matrix multiplication.

Algorithm for Homogenous Matrix between to planes:

1. Initialize the transformation matrix to \( T=I \), which corresponds to the orthonormal coordinate frames F and M being coincident.
2. Represent rotations and translations using separate homogeneous transformation matrices.
3. Represent composite rotations as separate fundamental homogeneous rotation matrices.
4. If the mobile co-ordinate frame $M$ is to be rotated about or translated along a unit vector of the fixed co-ordinate frame $F$, then pre-multiply.

5. If the mobile co-ordinate frame $M$ is to be rotated about or translated along one of its own unit vectors, then post-multiply.

6. If there are more fundamental rotations or translations to be performed, go to step IV; else stop.

The resulting composite homogeneous transformation matrix $T$ maps mobile $M$ co-ordinates onto fixed $F$ co-ordinates.

**Homogeneous Transformation Matrix: iARM Tool**

Let us consider the Tool of the iARM. Here we need to find the transformation matrix from the tool pitch i.e. joint 3 to the tool tip. Let us consider the frame 3 as fixed coordinate frame and frame 4 as mobile coordinate frame.

Here we perform all rotations and translation along fixed coordinate frame. Thus we perform following three steps to make mobile coordinate frame coincide with fixed coordinate frame.

1. Translation along $x^3$ by $P$
2. Rotation along $z^3$ by $\theta$
3. Rotation along $x^3$ by $\pi/2$

The Final matrix we obtain from this is as below

\[
\begin{bmatrix}
  C\theta & -S\theta & 0 & PC\theta \\
  -S\theta & -C\theta & 0 & -PS\theta \\
  0 & 0 & -1 & 0 \\
  0 & 0 & 0 & 1
\end{bmatrix}
\]

\[eq.1.0\]
**DIRECT KINEMATICS ANALYSIS**

**Definition**
Given vector of joint variables of a robotic manipulator, determine the position and orientation of the tool with respect to a coordinate frame attached to the robot base.

**Open Kinematic chain**

Mechanics of a manipulator can be represented as a kinematic chain of rigid bodies (links) connected by revolute or prismatic joints. One end of the chain is constrained to a base, while an end effector is mounted to the other end of the chain. The resulting motion is obtained by composition of the elementary motions of each link with respect to the previous one.

**Kinematics** describes the analytical relationship between the joint positions and the end-effectors position and orientation.
**Denavit - Hartenberg (D-H) Representation**

D-H algorithm is a systematic notion for assigning right-handed coordinate frames, one to each link in an open kinematic chain of links.

**Kinematic Parameters**

- Amount of **rotation** about $\mathbf{z}^{k-1}$ to make $\mathbf{x}^{k-1}$ parallel to $\mathbf{x}^k$ is called as **JOINT ANGLE** $\theta_k$

- Amount of **Translation** along $\mathbf{z}^{k-1}$ to make $\mathbf{x}^{k-1}$ intersect with $\mathbf{x}^k$ is called as **JOINT DISTANCE** $d_k$

- Amount of **rotation** about $\mathbf{x}^k$ to make $\mathbf{z}^{k-1}$ parallel to $\mathbf{z}^k$ is called as **LINK TWIST ANGLE** $\alpha_k$

- Amount of **Translation** along $\mathbf{x}^k$ to make $\mathbf{z}^{k-1}$ intersect with $\mathbf{z}^k$ is called as **LINK DISTANCE** $a_k$

**Tool**

Approach Vector $\mathbf{r}^3$ is aligned with the tool roll axis and points away from the wrist. Sliding vector $\mathbf{r}^2$ is aligned with the open-close axis of tool. Normal vector $\mathbf{r}^1$ is orthogonal to plane defined by approach and sliding vector and completes a right handed orthonormal coordinate frame.
**ARM Kinematic Analysis**

**Link Coordinate Diagram**

![Link Coordinate Diagram](image)

**Kinematic Parameter Table**

<table>
<thead>
<tr>
<th>Axis</th>
<th>θ</th>
<th>d</th>
<th>a</th>
<th>α</th>
<th>Home</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>θ₁</td>
<td>d₁</td>
<td>0</td>
<td>-π/2</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>θ₂</td>
<td>0</td>
<td>a₂</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>θ₃</td>
<td>0</td>
<td>a₃</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>θ₄</td>
<td>0</td>
<td>0</td>
<td>-π/2</td>
<td>-π/2</td>
</tr>
</tbody>
</table>
### The Arm Matrix

\[
T^{\text{Wrist}}_{\text{Base}} = T^T_0 T^T_1 T^T_2 T^T_3 =
\begin{bmatrix}
C_1 & 0 & -S_1 & 0 \\
S_1 & C_1 & 0 & 0 \\
0 & -1 & 0 & d_1 \\
0 & 0 & 0 & 1
\end{bmatrix} *
\begin{bmatrix}
C_2 & -S_2 & 0 & a_2 S_2 \\
S_2 & C_2 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix} *
\begin{bmatrix}
C_3 & -S_3 & 0 & a_3 S_3 \\
S_3 & C_3 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix} =
\begin{bmatrix}
C_1 C_2 - C_1 S_2 & -S_1 & a_2 C_2 C_2 & 0 \\
S_1 C_2 - S_1 S_2 & C_1 & a_2 S_1 C_2 & 0 \\
-S_2 & -C_2 & 0 & d_1 - a_2 S_2 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

From Eq1.0 we derive transformation matrix for transformation from Pitch to Tool.

\[
T^{\text{Tool}}_{\text{Wrist}} = T^T_3 =
\begin{bmatrix}
C_4 & -S_4 & 0 & PC_4 \\
-S_4 & -C_4 & 0 & -PS_4 \\
0 & 0 & -1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

The Final Transformation matrix can be obtained from Eq.1.1 and Eq.1.2

\[
T^{\text{Tool}}_{\text{Base}} = T^T_0 T^T_1 T^T_2 T^T_3 T^T_4 =
\begin{bmatrix}
C_1 C_{23} & -C_1 S_{23} & -S_1 & C_1 (a_2 C_2 + a_3 C_{23}) \\
S_1 C_{23} & -S_1 S_{23} & C_1 & S_1 (a_2 C_2 + a_3 C_{23}) \\
-S_2 & -C_{23} & 0 & d_1 - a_2 S_2 - a_3 S_{23} \\
0 & 0 & 0 & 1
\end{bmatrix} *
\begin{bmatrix}
C_4 & -S_4 & 0 & PC_4 \\
-S_4 & -C_4 & 0 & -PS_4 \\
0 & 0 & -1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

Final Transformation Matrix from Base to Tool.

\[
T^{\text{Tool}}_{\text{Base}} = T^T_0 T^T_1 T^T_2 T^T_3 T^T_4 =
\begin{bmatrix}
C_1 C_{23-4} & C_1 S_{23-4} & S_1 & C_1 (PC_{23-4} + a_2 C_2 + a_3 C_{23}) \\
S_1 C_{23-4} & S_1 S_{23-4} & -C_1 & S_1 (PC_{23-4} + a_2 C_2 + a_3 C_{23}) \\
-S_2 & C_{23-4} & 0 & PS_{23-4} + d_1 - a_2 S_2 - a_3 S_{23} \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

……eq.1.3
THE GRAPHICAL USER INTERFACE

TRIiceps Software developed for TRI Technosolutions shows a simple GUI interface for controlling the Robotic Manipulator. The TRIiceps shown here can only be used for Forward Kinematics. The newer version on TRIiceps with Inverse Kinematic analysis can be viewed on the website www.saurabhpalan.googlepages.com/iarm

a. User can use the sliders to vary the link angles and hence the coordinates.
b. Once you get the desired X-Y-Z coordinates, click on the 'Add' button to load the coordinates into the List box provided below the slider controls.

c. Repeat steps 'a' and 'b' to load a sequence of motions.

d. Once loaded, to execute all the coordinates and click on 'Execute'.
e. When the program is being executed a RED line appears at the bottom of the software. You cannot enter or modify the program until the line turns GREEN again.

f. You also have a provision to save a series of co-ordinates. The file is saved as .arm file.
g. You can use the save file immediately or save it for future use.

![File Saved!](image)

File Saved. Do you want to use on this File?

- Yes
- No

h. The saved file can then be loaded using ‘LOAD’ tab.

![Arm File Loaded!](image)
LAB EXPERIMENTS BASED ON IARM

1. **Study of Homogeneous Transformations**
   The tool pitch to Tool tip transformation of this robotics Arm is a very good platform to teach students concepts studied in text books and also showing them the application of the same in robot designing. The position matrixes of eq.1.0 to eq.1.3 are all the coordinate system positions of each joint of robot.

2. **Measurement of Robot Specifications**
   a. **Robot Reach and Stroke**
      This experiment aims at verifying or measuring the limits of the robot. The home position of the robot as per the software can be used to measure the horizontal reach of the robot. The vertical reach of the robot is also simple to find just by turning the shoulder angel of robot 90 degree from the home position. The horizontal and vertical stroke calculations can be a bit tricky. Let students experiment to find Stoke value and clear their concepts about the robot specifications.
   
   b. **Repeatability and Accuracy**
      A simple experiment as it may seem but this experiment can be useful to tech a very useful concepts of repeatability and accuracy of the robot which are very important parameters of designing a robot. The robot is preferred to have a high repeatability and accuracy. The repeatability can be found out by placing the tool tip at a position, move it to some other location and getting it back precisely at that position. Accuracy of the robot can be measured by setting the coordinates for the robot through software and verifying the actual position of the robot tool tip on the arena.

3. **Direct Kinematics Analysis of iARM**
   (Refer Page 24 for calculations)
   The aim of this experiment is to study the direct kinematics analysis of iARM through the D-H algorithm. The iARM robot is a four axis articulated R-R-R robot. It is an Education robot which implements RC servo motors for high torque and precise rotation. RC Servos are used to drive the joints directly. This eliminates the friction and backlash and allows for clear, precise and high speed operation.
The link co-ordinate diagram is constructed by applying the steps 0 to 7 of the D-H algorithm. The vector of joint variable is \( q = [\theta_1, \theta_2, \theta_3, \theta_4]^T \).

The values for joint distances \( d \) and link lengths of iARM robot are:

\[
d = [110, 0, 0, 0]^T
\]

\[
a = [0, 80, 60, 0]^T
\]

The iARM also consist of one more parameter \( P = [0, 0, 0, 150]^T \). Here the length between the Tool Pitch and the Tool does not qualify as joint distance nor as Link Length as per their definition. Thus \( a_4 \) and \( d_4 \) are both zero and we named the unknown length ‘\( P \)’.

Applying steps 8 to 13 of the D-H algorithm yields the kinematics parameters of the robot. It shows that iARM robot is kinematically tricky. The arm matrix is computed from the KP table.

4. Task Planning: Pick and Place operation

Aim of this experiment is to plan a task of picking a block from a predefined location and placing it at another position and then picking up another block from other predefined position and placing it on the top of the 1\textsuperscript{st} one within the robot workspace.

This experiment helps learn the concept of task planning and also help study the x-y-z coordinated characteristics of the robot.

An example of such an experiment is mentioned below.

Test coordinates

Place the arm and props on the demo charts, load the sequence given below and execute.

Demo 1 – To test X-Y coordinates

Place block 1 at \( X=20, Y=5 \) and block 2 at \( X=12, Y=17 \)
<table>
<thead>
<tr>
<th>Base</th>
<th>Shoulder</th>
<th>Elbow</th>
<th>Tool</th>
<th>Gripper</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
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Appendix - RC Servo motor

Servo motors are devices which provide precise position control through feedback. RC Servos (Remote /Radio Controlled Servos) as name suggest, are widely used in remote controlled cars (for steering control) and planes (for flap adjustment). RC Servos can rotate only 180 degree and have wide applications in robotics. These servos are used for application like robotic arms and humanoid.

RC servos consist of a DC motor, gearbox, control circuit and feedback devices. The feedback device (mostly potentiometer) is mechanically coupled to the output shaft. The control signal (PWM signal) proportional to the required shaft position is given to the servo.

The PWM signal is converted into a voltage corresponding to the desired position. The output voltage also changes in proportion to the actual shaft position. These two will have same value if the position of the shaft is at the desired position. If the position of the shaft is not the same as desired position then an error voltage is generated which will move the motor until the desired position is obtained.

The RC Servo motors require a PWM having time period of around 20ms is required and the pulse width of 1-2ms. 1ms pulse width corresponds to 0 degree and 2ms pulse width corresponds to 180 degree. For any other angle between 0 degree and 180 degree corresponding pulse width is required.
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The RC servo has three wires, one for control signal and others for power supply (Vcc and Gnd).
Operating voltage or supply voltage is in the range of 4.8v to 6v