



DesignNews

Modeling Robot Kinematics using Python and AI

DAY 1 : Introduction to Robotics and Kinematics

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Dr. Don Wilcher

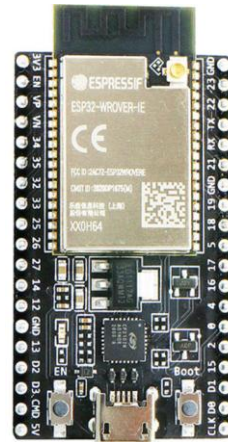
Visit 'Lecturer Profile' in your console for more details.

Course Kit and Materials

Adept 5-DOF Robot Arm Kit



ESP32-DEVKITC-VIE



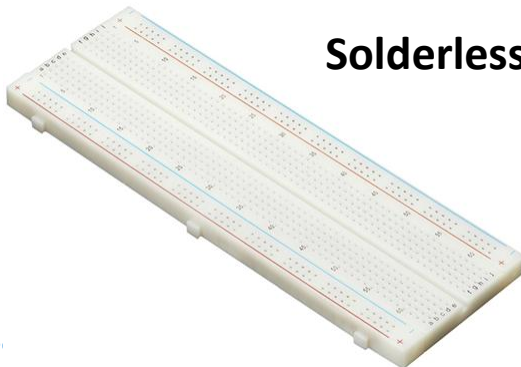
9G SERVO MOTOR KIT 180DEG



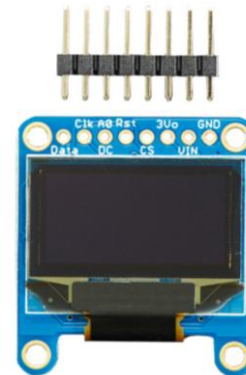
Adafruit Parts Pal Kit



Solderless Breadboard x2



OLED Display



Course Kit and Materials

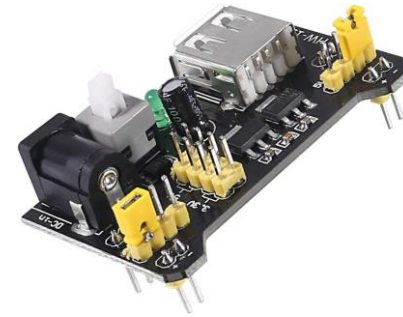
Jumper Wires: Male to Male



Jumper Wires: Male to Female



Solderless Breadboard Power Supply



18650 Rechargeable Battery



Research Perspective

- “Robotics is the art, knowledge base, and know-how of designing, and applying, and using robots in human endeavors (Niku, 2020).”
- “Using matrices, we first establish a method of describing objects, locations, orientations, and movements (Niku, 2020).”

Agenda:

- Key Terms and Definitions
- Major Robot Components
- Matrices and Modeling
- Lab: Build the Adept Robotics Arm

Key Terms and Definitions

1. Robotics

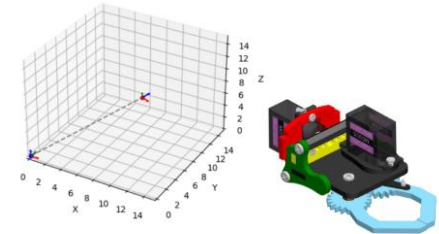
Robotics is the interdisciplinary field that involves the design, construction, operation, and use of robots. It combines elements of mechanical engineering, electrical engineering, computer science, and control systems to create machines that can perform tasks autonomously or with human guidance.

2. Inverse Kinematics (IK)

Inverse Kinematics is the process of calculating the joint angles of a robot given a desired end-effector position and orientation. It is essential for motion planning and allows a robot to determine how to move its joints to achieve a specific goal.

3. Forward Kinematics (FK)

Forward Kinematics is the process of determining the position and orientation of a robot's end-effector based on given joint parameters (angles or displacements). It follows a direct mathematical model of the robot's structure.



Key Terms and Definitions...

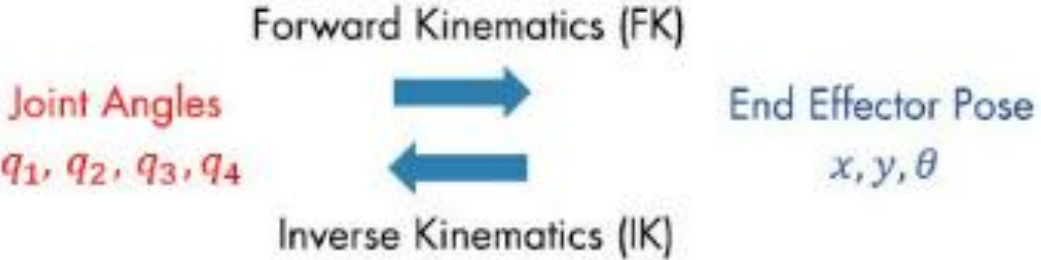
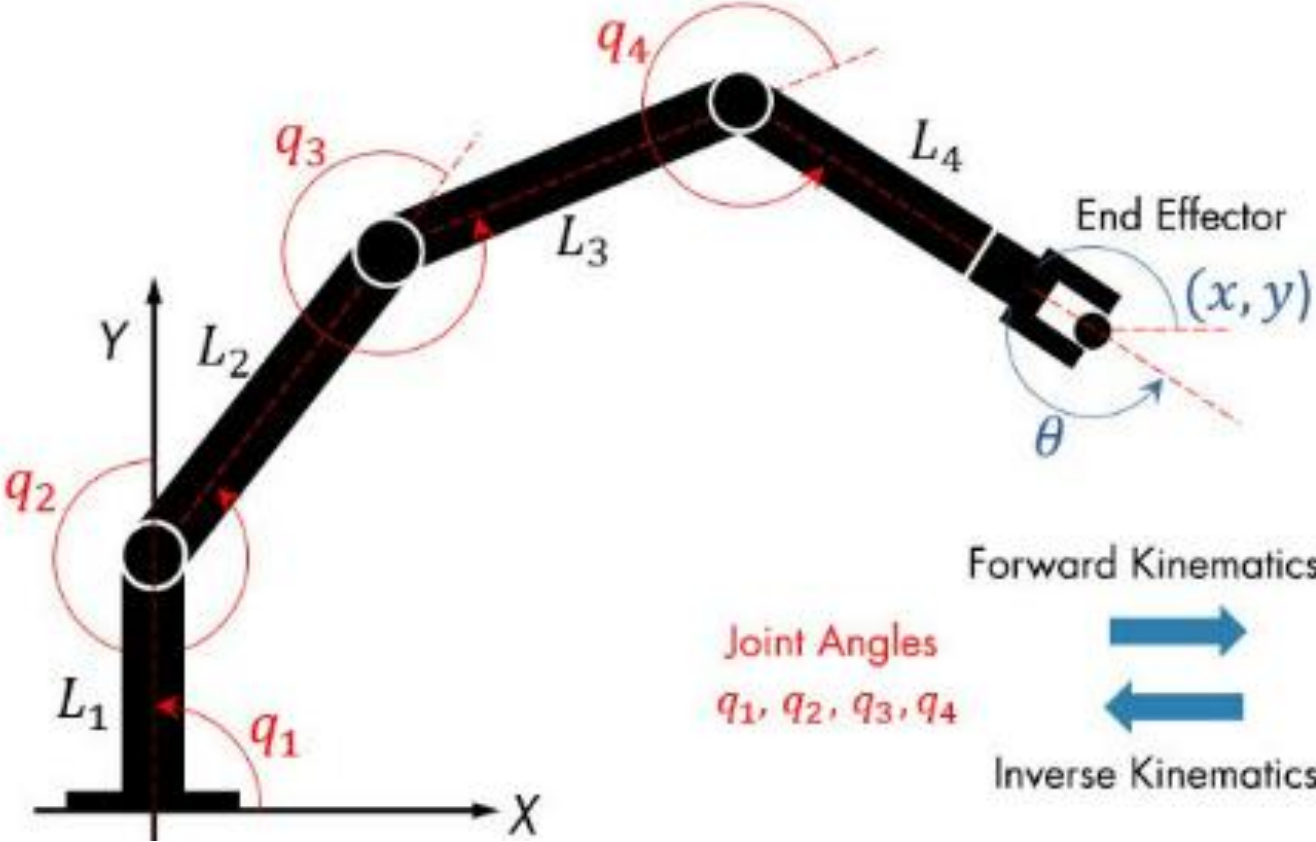
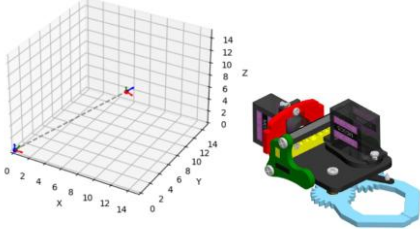


Image: [Mathworks](#)

Key Terms and Definitions . . .

4. Revolute

A revolute joint is a type of robotic joint that allows rotational motion around a fixed axis. It is commonly found in robotic arms and mimics the movement of a human elbow or wrist.

5. Prismatic

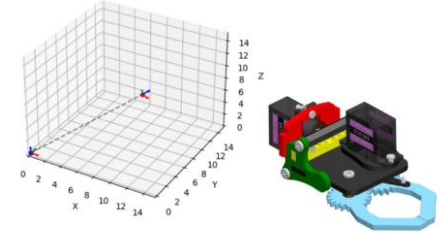
A prismatic joint is a type of robotic joint that allows linear motion along a single axis. It is often used in robotic systems that require sliding movements, such as telescopic mechanisms.

6. Actuators

Actuators are components that provide movement in a robotic system. They convert electrical, hydraulic, or pneumatic energy into mechanical motion and can be rotary (motors) or linear (pistons).

7. Controller

A controller is the device or software that governs a robot's behavior by processing inputs from sensors and generating appropriate commands for actuators. It is responsible for executing control algorithms and ensuring that the robot follows the desired trajectory or task.



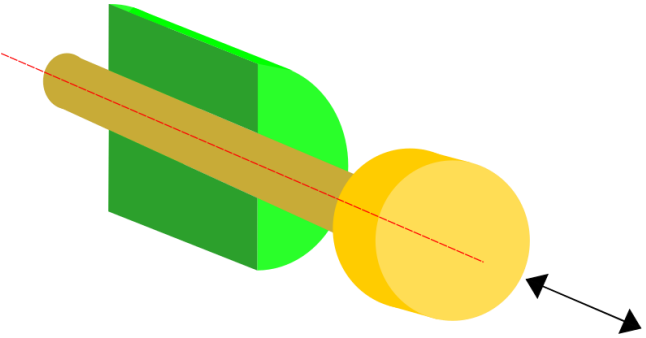
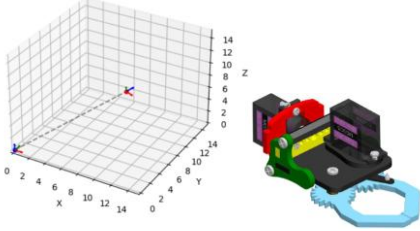
Question 1

What is a Prismatic Joint?

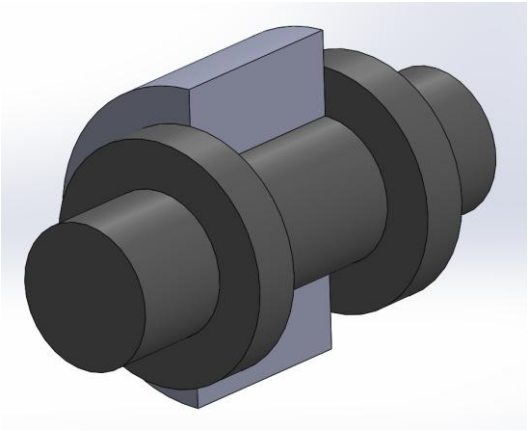
- a) A robotic joint that allows rotary motion along a single axis.**
- b) A robotic joint that provides movement in a robotic system.**
- c) A robotic joint that allows linear motion along a single axis.**
- d) none of the above**



Key Terms and Definitions ...



Prismatic Joint: Slider or Sliding Pair



Revolute Joint: Pin or Hinge Joint

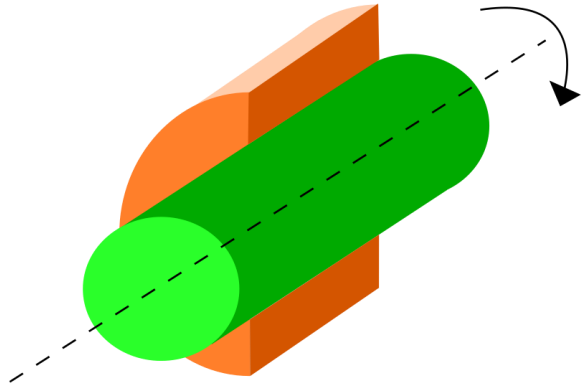
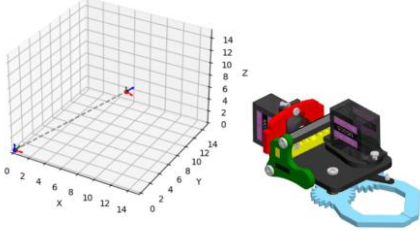


Image: [Wikipedia](#)

Key Terms and Definitions ...



SCARA (Selective Compliance Assembly Robot Arm) Robot Configuration

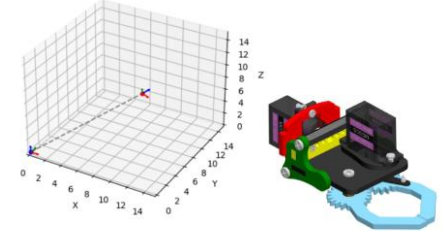
Revolute Joints:
A & B

Image: [Fanuc Europe](#)



Prismatic Joint

Key Terms and Definitions ...



Electric Rotary Actuator:
Revolute Joint



Electric Linear Actuator:
Prismatic Joint



Image: [FESTO](#)

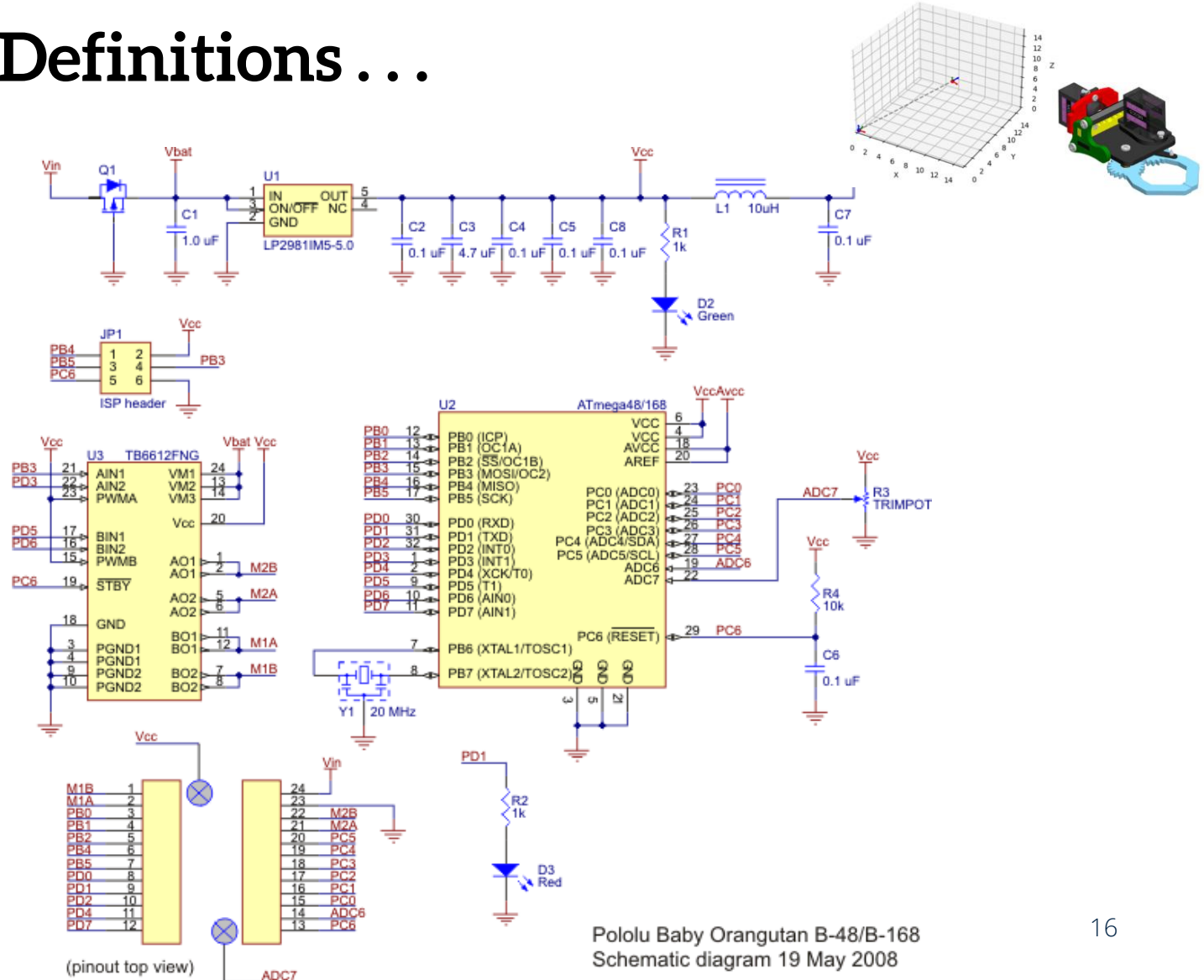
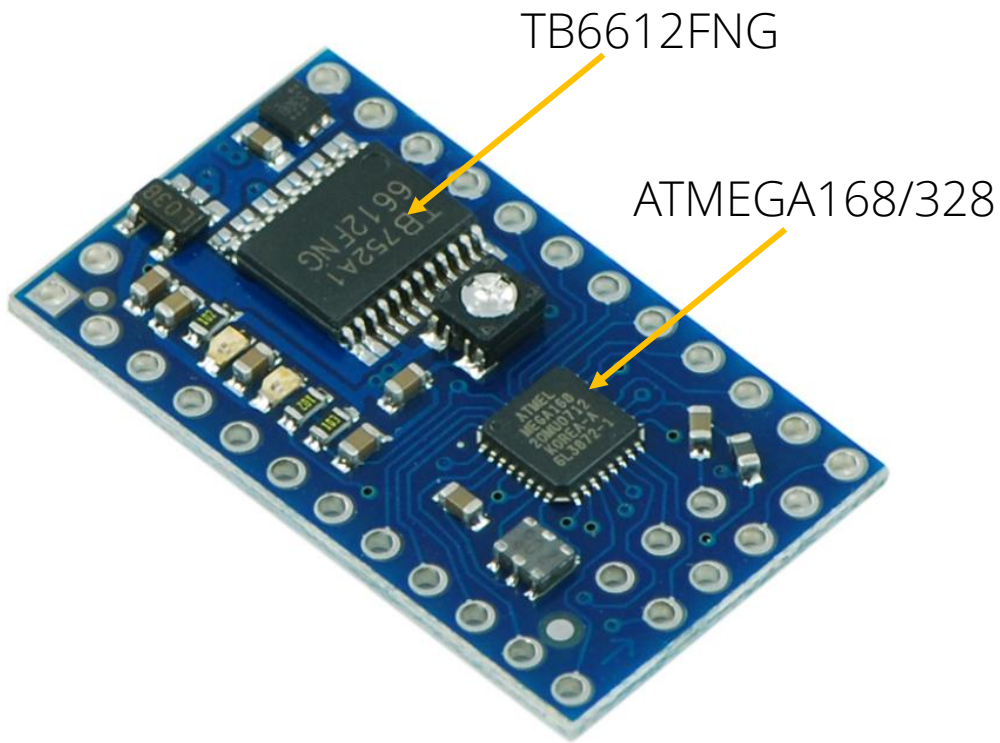
Question 2

What two technical joints for motion are used by a SCARA Robot?

- a) linear and rotary**
- b) slider and rotation**
- c) prismatic and revolute**
- d) none of the above**



Key Terms and Definitions ...



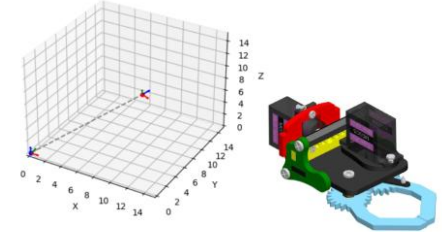
Pololu Baby Orangutan B-48/B-168 Schematic diagram 19 May 2008

Baby Orangutan Robot Controller

Image: Pololu
Information Classification: General

Key Terms and Definitions . . .

What is Degrees Of Freedom?



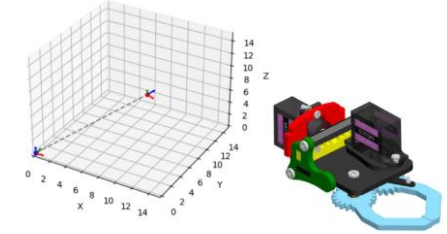
Degrees of Freedom (DOF) in robotics refers to the number of independent movements a robot or robotic joint can make. Each DOF represents a way the robot can move or rotate in space.

Types of Degrees of Freedom:

1. Translational DOF (Linear Movement) – Motion along the X, Y, or Z axes.
2. Rotational DOF (Angular Movement) – Rotation around the X, Y, or Z axes.

Key Terms and Definitions . . .

What is Degrees Of Freedom?



DOF in Robotic Arms:

- A simple robotic arm typically has 6 DOF (three for positioning and three for orientation):
 1. Moving up/down (along the Z-axis)
 2. Moving left/right (along the X-axis)
 3. Moving forward/backward (along the Y-axis)
 4. Rotating around the X-axis (roll)
 5. Rotating around the Y-axis (pitch)
 6. Rotating around the Z-axis (yaw)

A robot with **fewer than 6 DOF** may have limited movement, while a robot with **more than 6 DOF** (e.g., humanoid robots) has extra flexibility for complex tasks.

Key Terms and Definitions ...

What is Degrees Of Freedom?

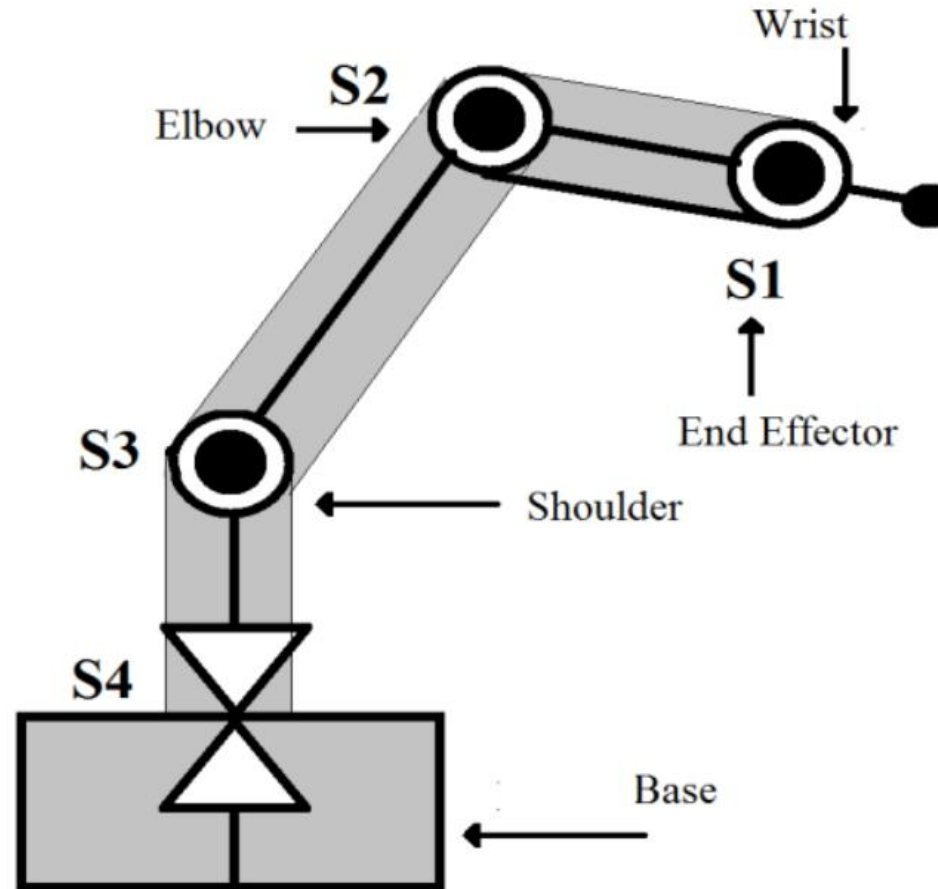
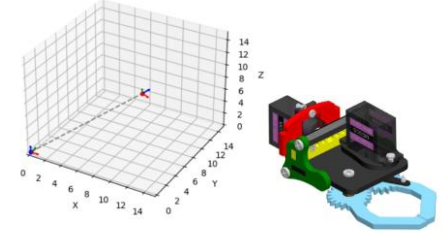


Image: [ResearchGate](#)

Information Classification: General

Question 3

In reviewing slide 19, what is the DoF for the robot shown?

- a) 2**
- b) 5**
- c) 4**
- d) none of the above**



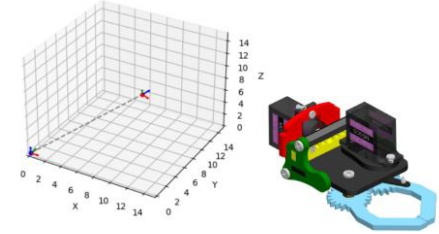
Major Robot Components

The major components of a robot include:

1. **Body/Frame** – The structural framework that supports all other components and determines the robot's shape, size, and physical capabilities.
2. **Actuators** – The motors or mechanisms that drive movement in the robot. They can be electric (DC/servo motors), hydraulic, or pneumatic.
3. **Sensors** – Devices that provide feedback about the robot's environment and internal state.

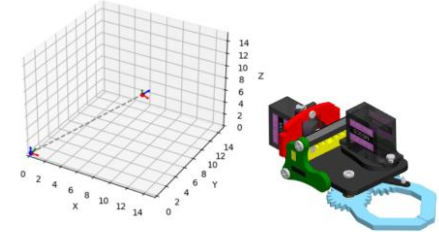
Common sensors include:

- **Proximity Sensors** (detect objects)
- **Encoders** (measure position/rotation)
- **IMUs (Inertial Measurement Units)** (detect motion and orientation)
- **Cameras & LiDAR** (for vision and navigation)

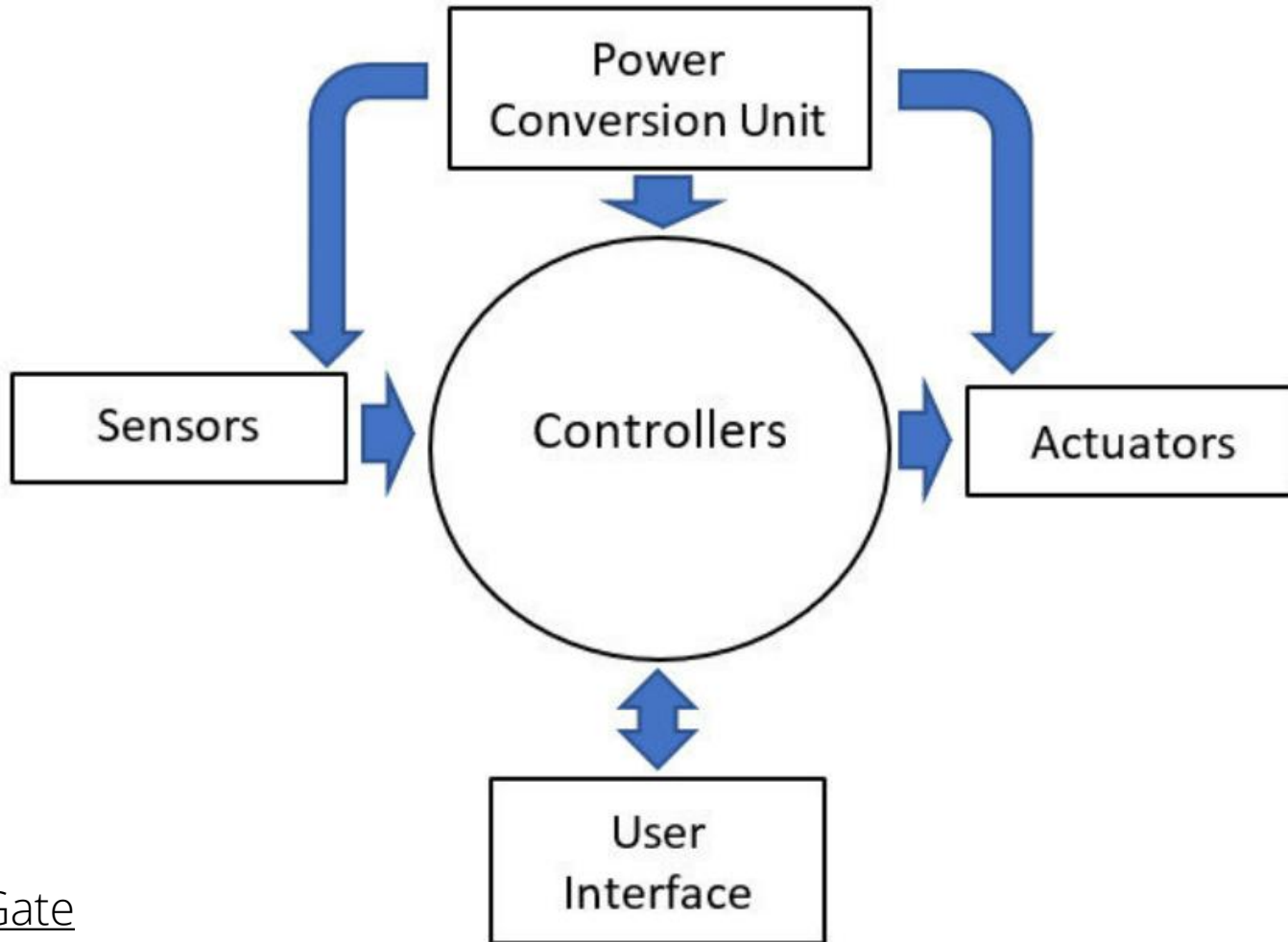
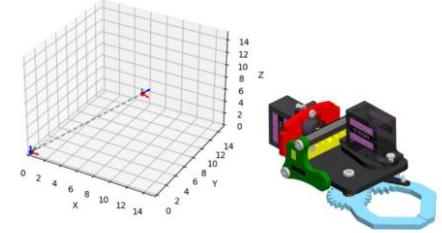


Major Robot Components. . .

4. **Power Supply** – Provides the necessary energy for the robot's operation. This can be batteries, wired power, or other energy sources like fuel cells.
5. **Controller (Processing Unit)** – The brain of the robot, responsible for decision-making and executing control algorithms. This can be a microcontroller (e.g., Arduino, ESP32) or a full computer (e.g., Raspberry Pi, industrial PC).
6. **End Effectors** – Tools or attachments at the robot's extremity that allow it to perform tasks. Examples include grippers, robotic hands, welding tools, and suction cups.
7. **Communication System** – Allows data exchange between the robot and other systems or operators. Communication methods include Wi-Fi, Bluetooth, serial communication (UART, SPI, I2C), and industrial networks (CAN, Modbus, EtherCAT).
8. **Software & Control Algorithms** – Programs that define the robot's behavior, including motion planning, machine learning, artificial intelligence, and real-time control.

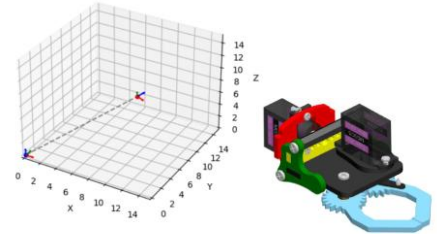
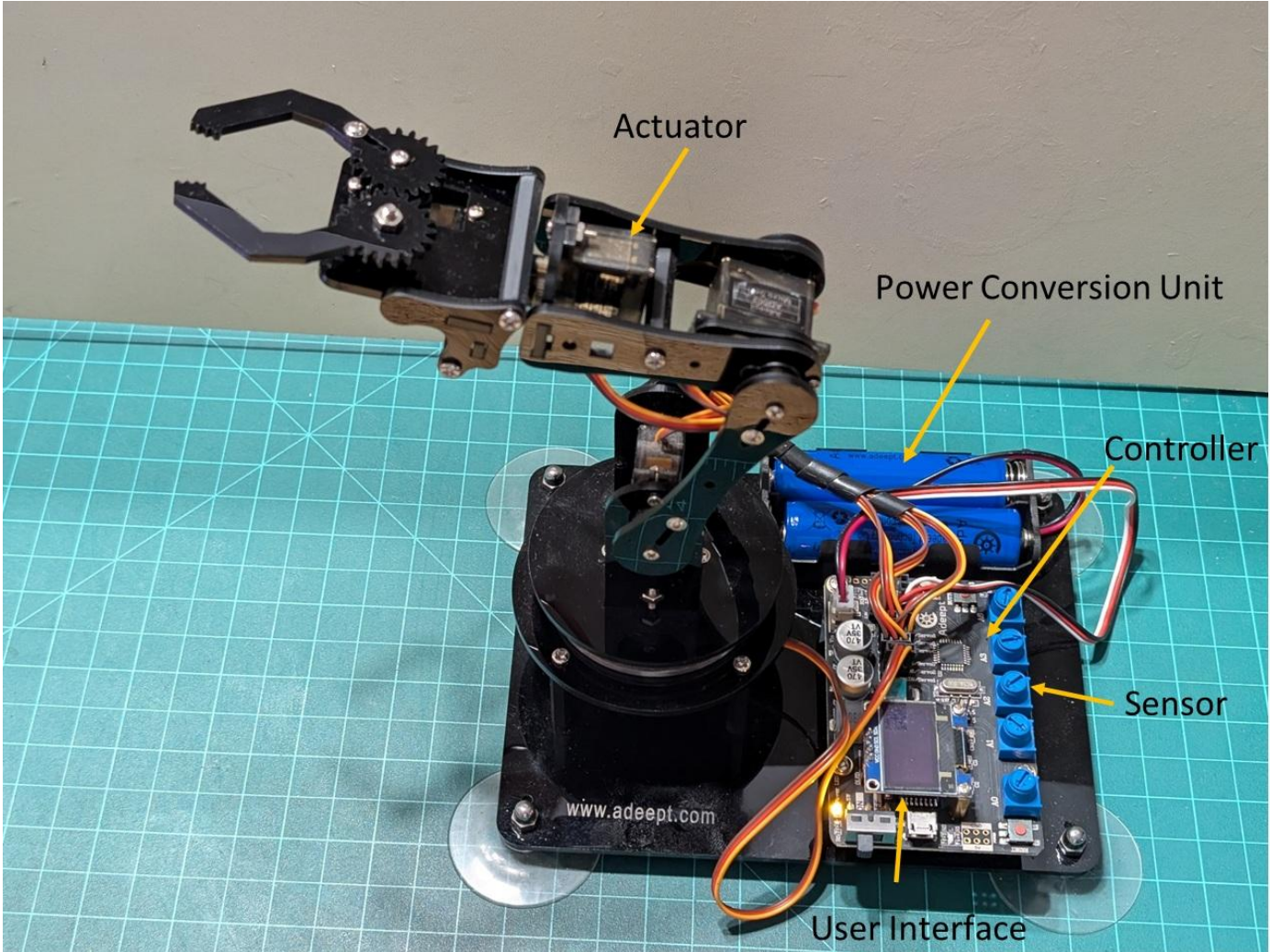


Major Robot Components...

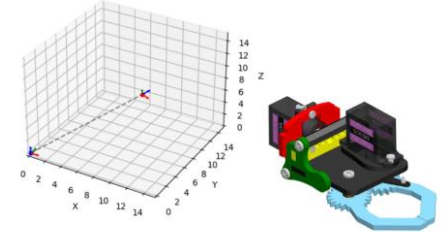


Major Robot Components...

Adept Robotic Arm Kit:
5 DoF



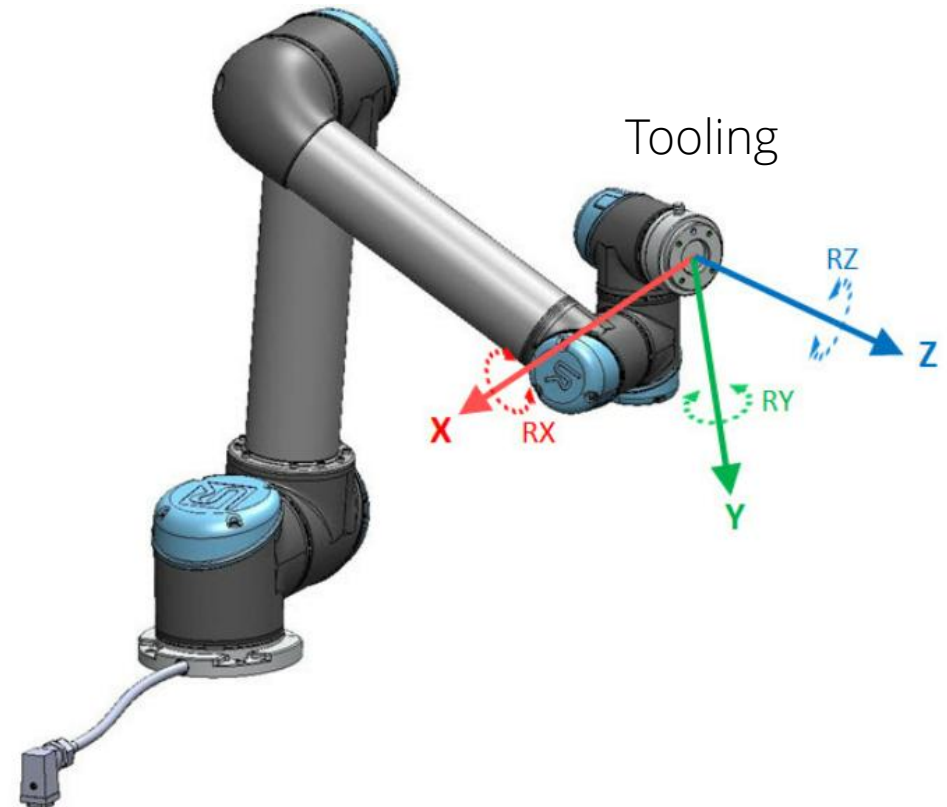
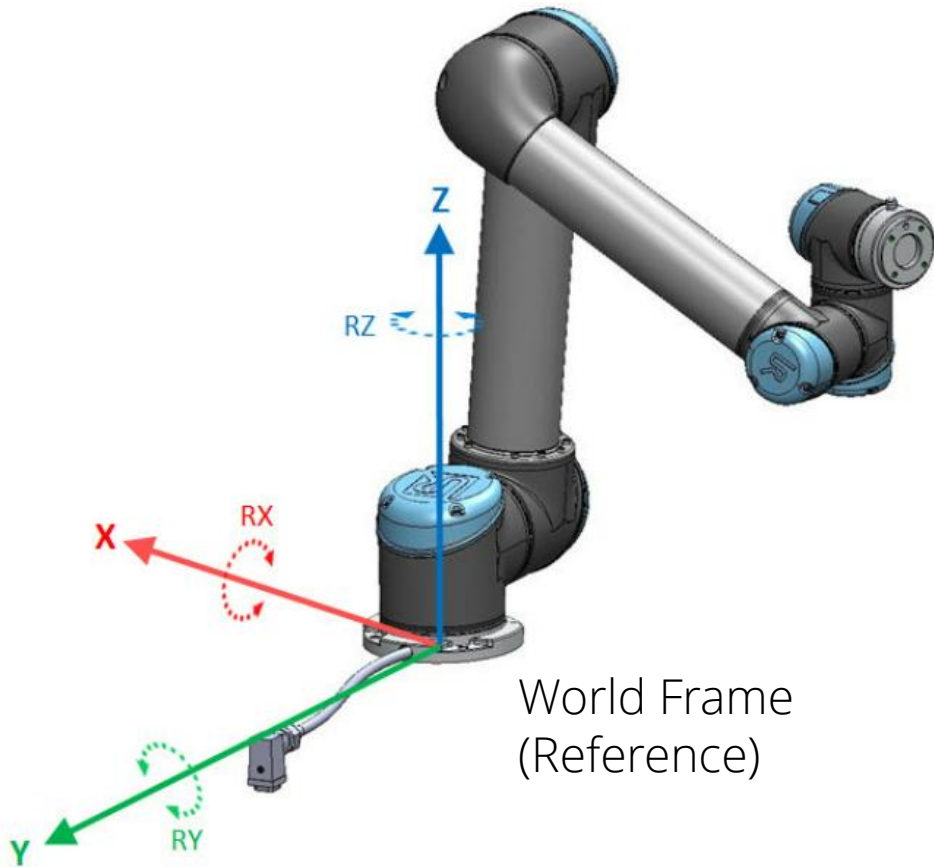
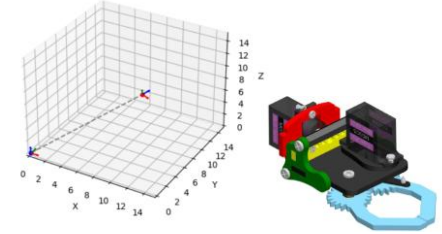
Matrices and Modeling



In robotics, transformations involving **translation** and **rotation** are typically represented using **homogeneous transformation matrices**. These matrices allow us to describe the position and orientation of a robotic arm's end-effector in space.

Matrices and Modeling

Robot Coordinate System



Matrices and Modeling...

1. Translation Matrix

Translation moves a point or an object in space without rotation. The translation matrix for movement along the X, Y, and Z axes is given as:

$$T = \begin{bmatrix} 1 & 0 & 0 & X \\ 0 & 1 & 0 & Y \\ 0 & 0 & 1 & Z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

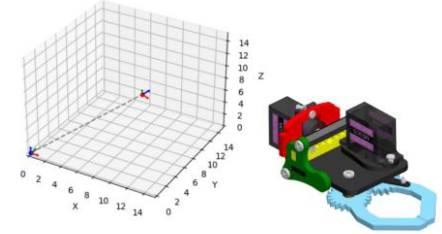
where:

- X, Y, Z are the translation distances along the respective axes.

Applying this matrix to a point $P [P_x, P_y, P_z, 1]^T$ results in:

$$P' = T \cdot P$$

which gives the new translated position.



Matrices and Modeling...

2. Rotation Matrices

Rotations occur around the X, Y, or Z axes and are represented as 3×3 sub-matrices in a 4×4 homogeneous transformation matrix.

Rotation About the X-Axis

$$R_x(\theta) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos \theta & -\sin \theta & 0 \\ 0 & \sin \theta & \cos \theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

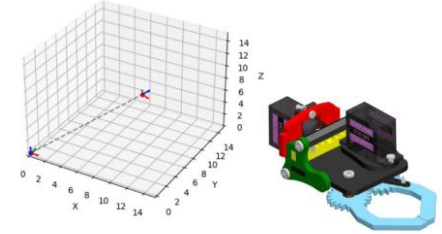
Rotation About the Y-Axis

$$R_y(\theta) = \begin{bmatrix} \cos \theta & 0 & \sin \theta & 0 \\ 0 & 1 & 0 & 0 \\ -\sin \theta & 0 & \cos \theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Rotation About the Z-Axis

$$R_z(\theta) = \begin{bmatrix} \cos \theta & -\sin \theta & 0 & 0 \\ \sin \theta & \cos \theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

where θ is the angle of rotation.



Matrices and Modeling...

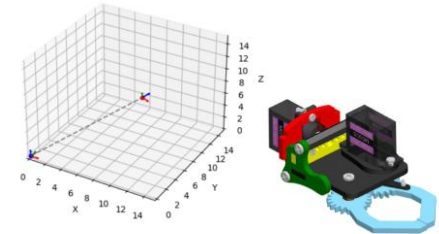
3. Homogeneous Transformation Matrix

A complete transformation combining rotation and translation is:

$$T = \begin{bmatrix} R_{3 \times 3} & \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \\ 0 & 1 \end{bmatrix}$$

For example, a transformation that rotates about Z and translates in XYZ is:

$$T = \begin{bmatrix} \cos \theta & -\sin \theta & 0 & X \\ \sin \theta & \cos \theta & 0 & Y \\ 0 & 0 & 1 & Z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



Matrices and Modeling...

4. Forward Kinematics (FK) using Transformation Matrices

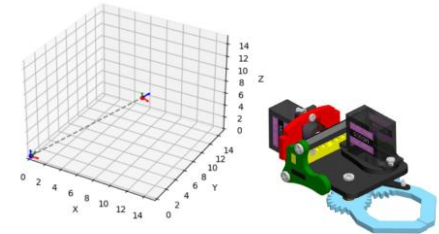
For a multi-link robotic arm, transformations for each joint are computed as:

$$T_{total} = T_1 \cdot T_2 \cdot T_3 \cdots T_n$$

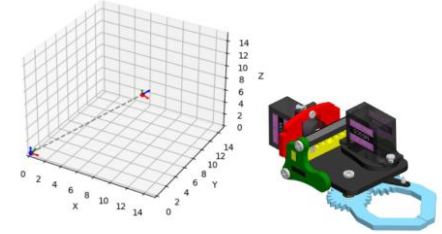
where each T_i represents the transformation matrix of a specific joint.

Summary

- Translation moves an object in space.
- Rotation changes orientation around an axis.
- Homogeneous transformation matrices combine both.
- Forward kinematics is computed by multiplying successive transformation matrices.



Matrices and Modeling...



Point Matrix in Robotics

A **point matrix** represents the position of a point in 3D space using homogeneous coordinates. This is useful in robotics for performing **translation, rotation, and scaling** using matrix operations.

Matrices and Modeling...

1. Definition of a Point Matrix

A point in 3D Cartesian space is represented as:

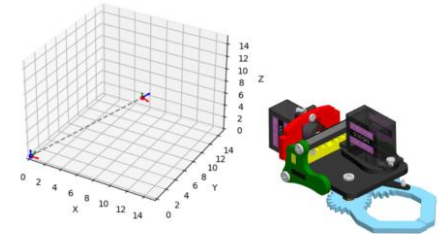
$$P = \begin{bmatrix} P_x \\ P_y \\ P_z \end{bmatrix}$$

To make it compatible with **homogeneous transformation matrices**, we extend it to **homogeneous coordinates** by adding an extra dimension:

$$P = \begin{bmatrix} P_x \\ P_y \\ P_z \\ 1 \end{bmatrix}$$

where:

- P_x, P_y, P_z are the coordinates of the point in 3D space.
- The **extra '1'** is a homogeneous coordinate used to apply transformations using **4x4 transformation matrices**.



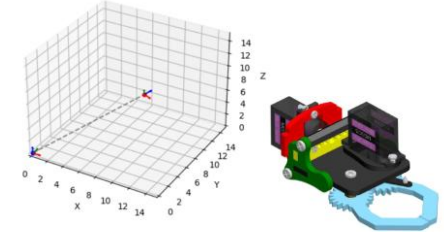
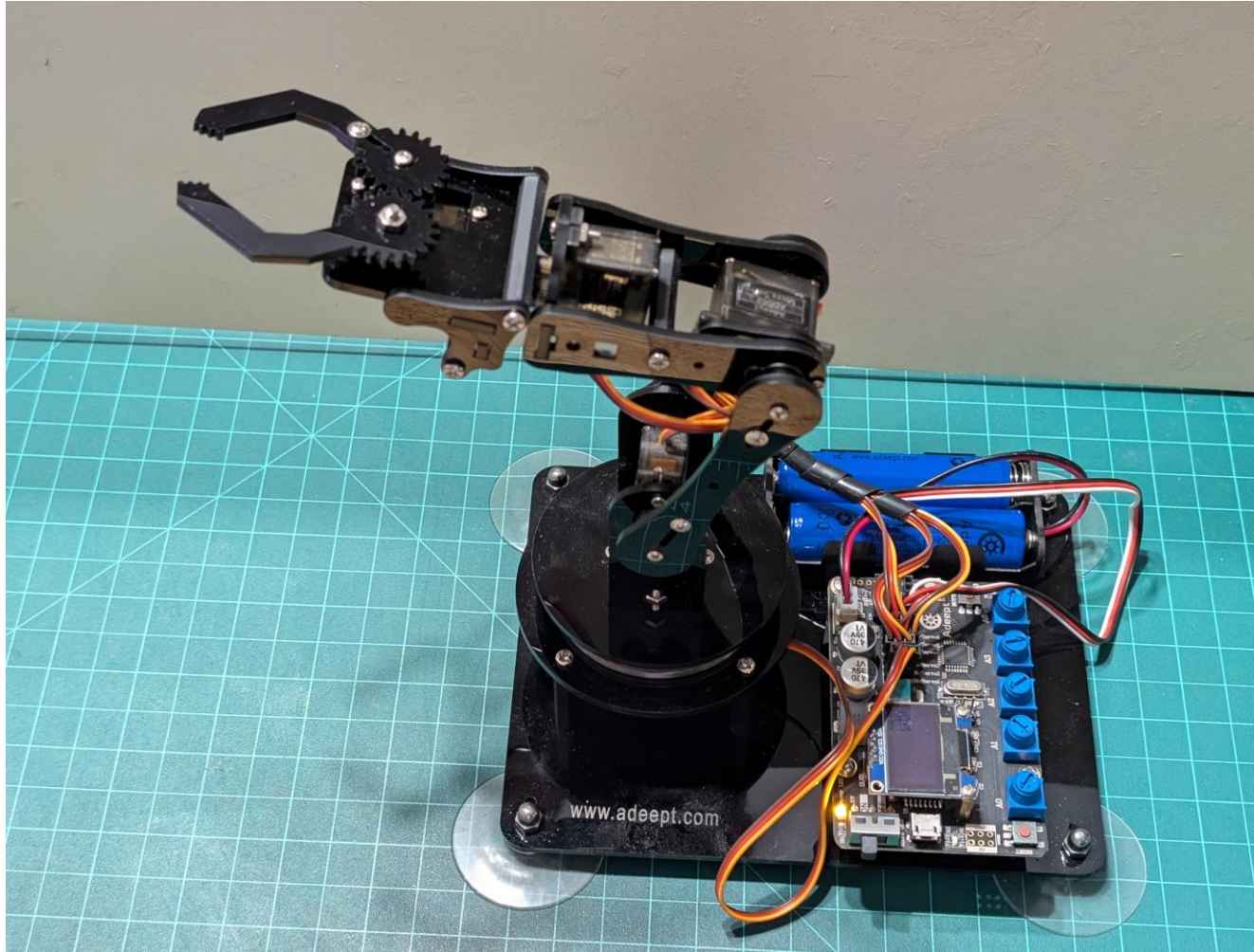
Question 4

Which matrix is used to move a point without rotation?

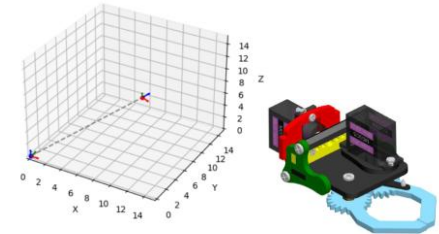
- a) linear**
- b) point**
- c) translation**
- d) none of the above**



Lab: Build the Adept Robotics Arm



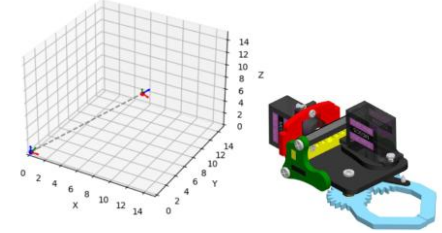
Lab: Build the Adeep Robotics Arm



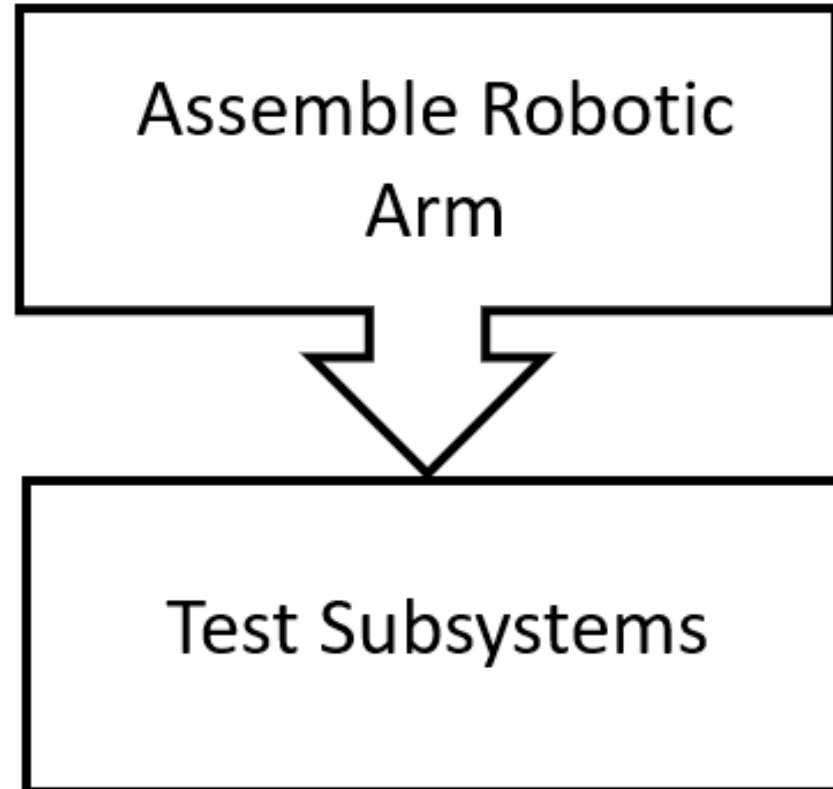
Participant Learning Objectives:

- Participants will learn to build the Adeep Robotic Arm.
- Participants will learn to test the subsystems and components of the Adeep Robotic Arm.
- Participants will learn to test the Adeep Robotic Arm.

Lab: Build the Adept Robotics Arm...

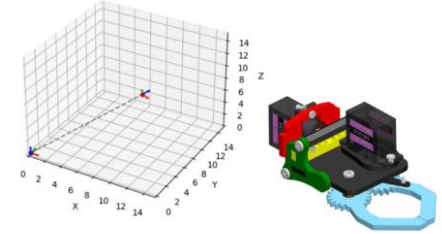
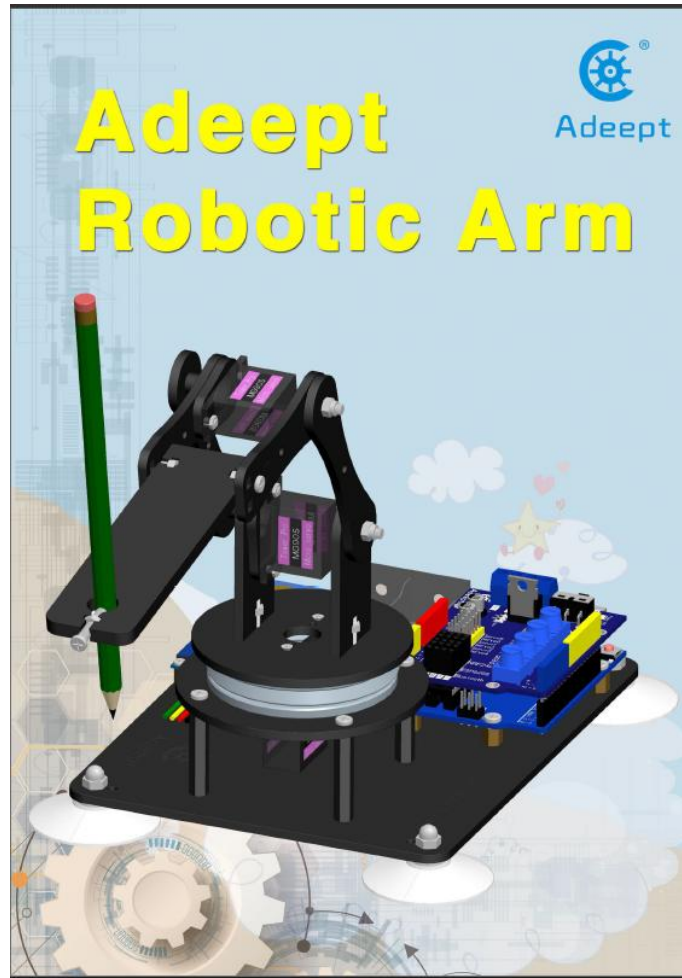


Build Plan

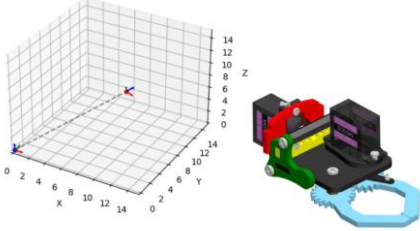


Lab: Build the Adept Robotics Arm...

Assembly and Lab Manual



Lab: Build the Adept Robotics Arm. . .



Build Plan

Assemble Robotic Arm Instructions:

Lesson 6: How to Assemble the Robotic Arm..... page 62

Test Subsystems:

Lesson 0: Building the Arduino Development Environment..... page 11

Lesson 1: How to Read the Data of the Potentiometer.....page 33

Lesson 2: Controlling the Servo.....page 40

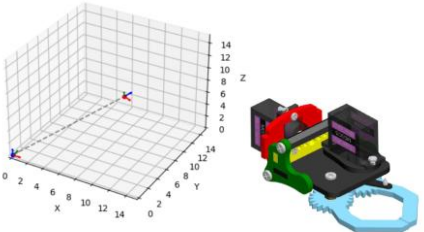
Lesson 3: Displaying Text on the OLED Screen.....page 47

Lesson 4: Saving Data with EEPROM.....page 52

Lesson 5: Servo 90-degree adjustment.....page 58

Lab: Build the Adept Robotics Arm...

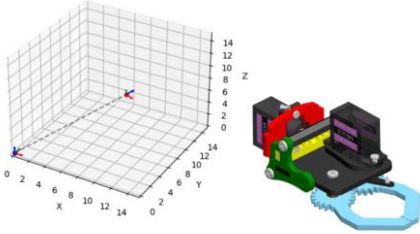
Packing List



Build Plan

Adept Robotic Arm Drive Board x1 	<p>OLED×1</p>	<p>Ribbon×1</p>	<p>18650 Battery Holder×1</p>	<p>A0002 Servo Motor×6</p>
	<p>Extension Cable for Servo×1</p>	<p>USB Cable×1</p>	<p>Large Cross-head Screwdriver×1</p>	<p>Small Cross-head Screwdriver×1</p>
Acrylic Parts 	<p>Cross Socket Wrench×1</p>	<p>Sucking Disc ×4</p>	<p>M2 Nut ×11</p>	<p>M3 Lock Nut×3</p>
	<p>M3 Nut×10</p>	<p>Self-Tapping Screw ×2 M1.4×6</p>	<p>M2 14 Screw ×7</p>	<p>M2 10 Screw×4</p>
<p>M2 5 Screw×4</p>	<p>M2.5 7 Screw ×5</p>	<p>M3 8 Screw ×24</p>	<p>M3 12 Screw×7</p>	
<p>M3 18 Screw ×2</p>	<p>M3 10 Countersunk Head Screw×9</p>	<p>M2 11 Copper Standoff×2</p>	<p>M3 8 Copper Standoff×1</p>	
<p>M3 15 Nylon Standoff×4</p>	<p>M3 30 Nylon Standoff×5</p>	<p>M3 40 Nylon Standoff×2</p>	<p>Bearing Turntable×1</p>	

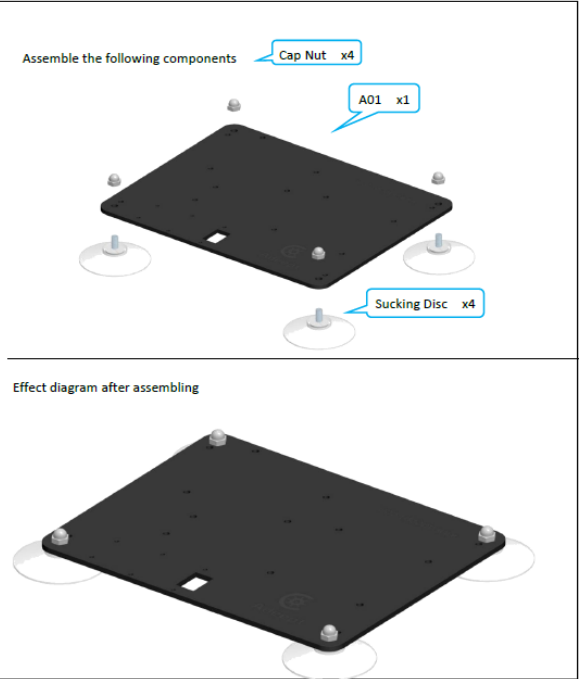
Lab: Build the Adept Robotics Arm...



Lesson 6 How to Assemble the Robotic Arm

6.1 Pedestal Assembly

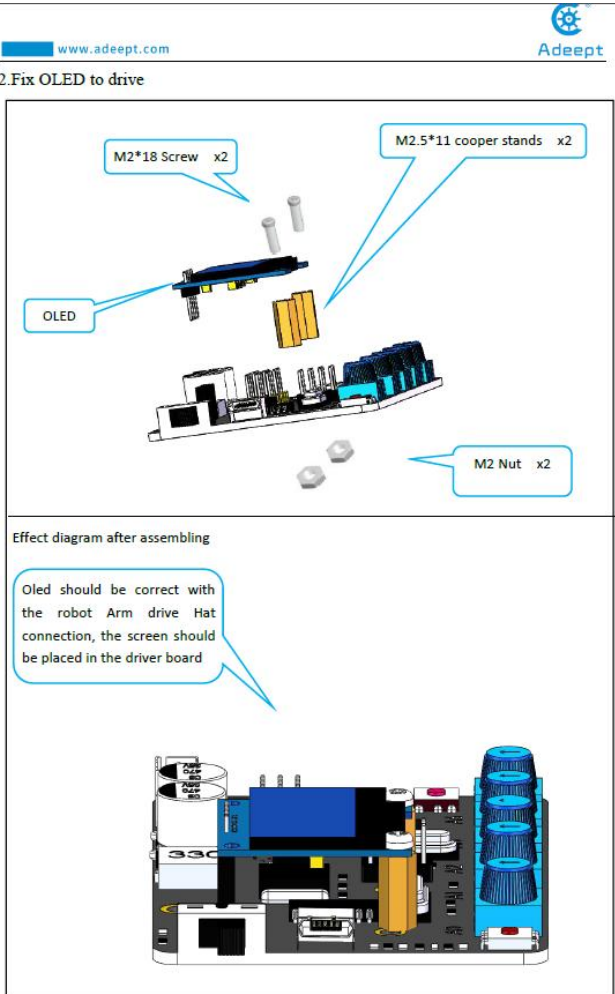
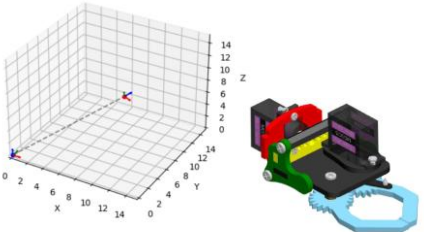
1. Fix four Sucking Discs on the four corners of A01.



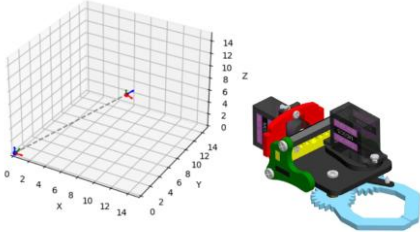
Partial Robotic Arm Build

Lab: Build the Adept Robotics Arm...


Partial Robotic Arm Build



Lab: Build the Adept Robotics Arm...



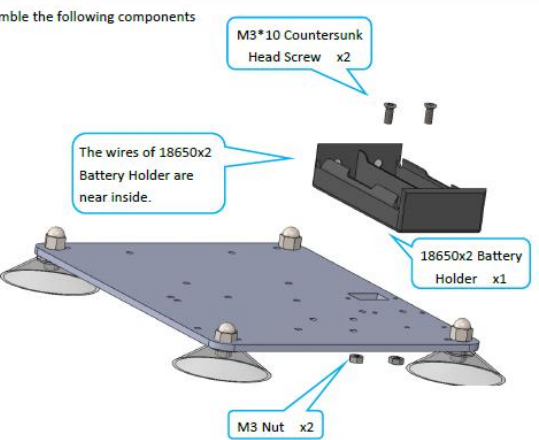
Partial Robotic Arm Build

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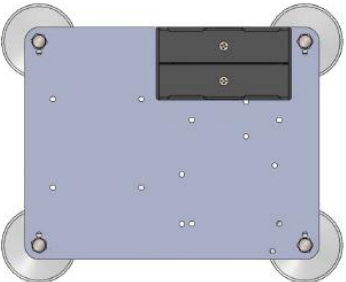
3. Fix 18650x2 Battery Holder to A01.

Assemble the following components

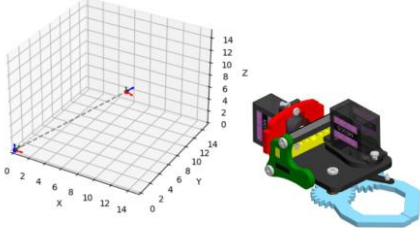
- M3*10 Countersunk Head Screw x2
- The wires of 18650x2 Battery Holder are near inside.
- 18650x2 Battery Holder x1
- M3 Nut x2



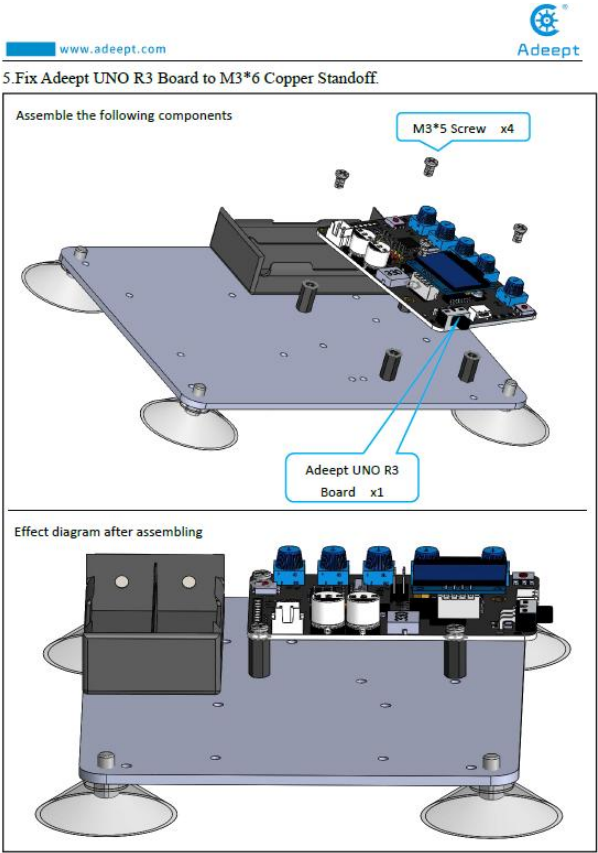
Effect diagram after assembling



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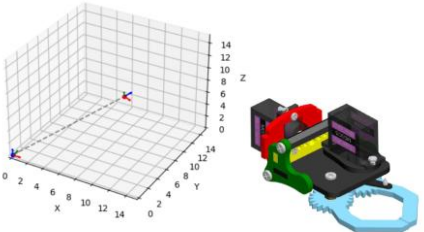
Partial Robotic Arm Build



6. Fix four M3*30 Nylon Standoffs to A01.

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Partial Robotic Arm Build



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6.1.3 Turnplate and Rocker Arm Assembly

Servo debugging (If you have already adjusted the steering gear to 90 degrees according to Lesson 5, then you don't need to adjust it anymore, please proceed to the next part)

Connect five servos to the Adept Arm Drive Board.

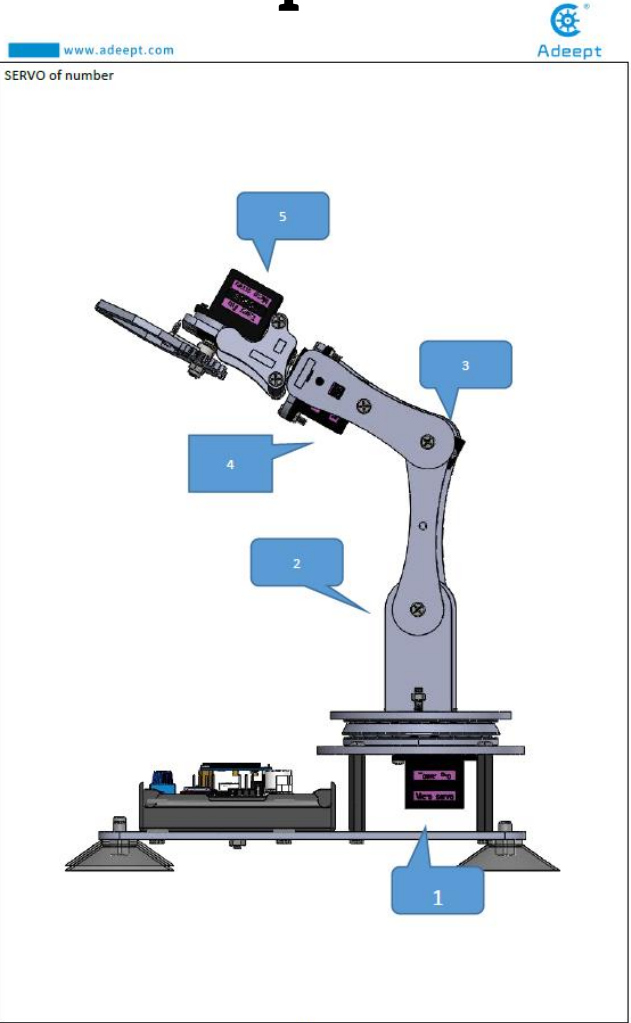
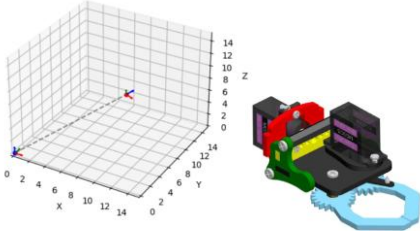
For convenience to read, only one end of the servo power cable is shown here.

Connect No. 1-5 servo, and increase from No. 1-5 in the direction close to the oled screen. Note that the direction of the Servo interface should not be reversed

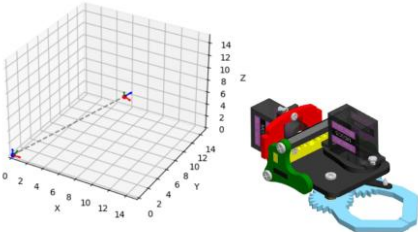
This is the No. 1 servo

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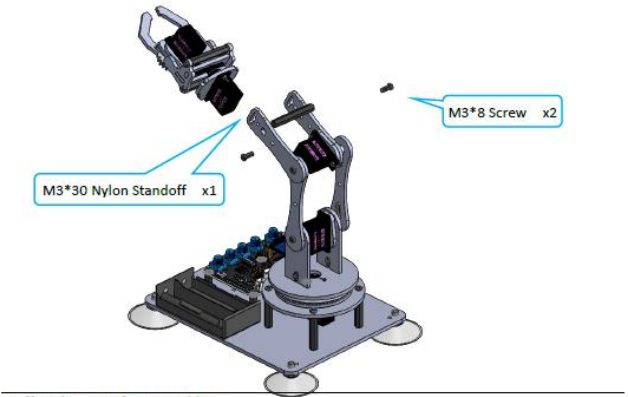


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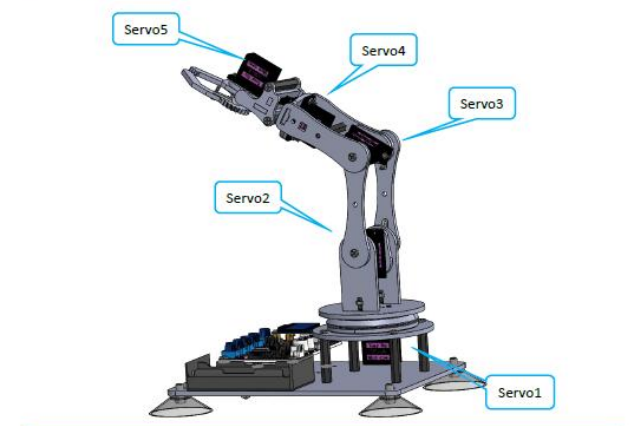


Partial Robotic Arm Build

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 Install the clamp section on the robotic arm.
 Assemble the following components



Effect diagram after assembling



Number each servo to prepare for the circuit connection.

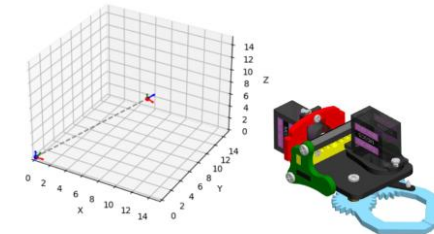
Question 5

In reviewing slide 46, which component is being attached to the robotic arm?

- a) tooling**
- b) effect-tool**
- c) end effector**
- d) none of the above**



Lab: Build the Adept Robotics Arm



Assembled and
Functional Robotic Arm

Watch the Video Clip!

<https://www.youtube.com/watch?v=GkraSsXS0XM>



Thank you for attending

Please consider the resources below:

Niku, S. B. (2020). Introduction to robotics: Analysis, control, applications (3rd ed.). Wiley



Thank You

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