

CHAPTER 12

CORDINATE SYSTEMS

Learning Outcomes

- Frame in Robotics
- Types of Frame
- Types of Material
- Types of Wheel

Robots need a way to understand their position and move correctly. To do this, they use **coordinate systems**, which help define locations in space. Different types of coordinate systems are used depending on how the robot moves and where it works. The three main types are **Cartesian, polar, and cylindrical coordinates**. Each of these helps a robot move and position itself in different ways, making them useful for various tasks.

Coordinate Systems in Robotics

Robots need to move accurately and efficiently in their workspace to complete various tasks. To describe their position and movement, they rely on **coordinate systems**, which provide a mathematical way to define locations in space. Different types of coordinate systems are used depending on the type of robot, its movement, and its work environment.

The three most commonly used coordinate systems in robotics are:

1. **Cartesian coordinate system** – Defines positions using straight-line distances along perpendicular axes.
2. **Polar coordinate system** – Represents positions using an angle and a distance from a central point.
3. **Cylindrical coordinate system** – Combines polar and Cartesian systems to define positions with an angle, a radius, and a height.

1. Cartesian Coordinate System

The **Cartesian coordinate system** is the most widely used system in robotics. It is based on a **rectangular grid** formed by three perpendicular axes:

- **X-axis** – Represents movement in the left-right direction.
- **Y-axis** – Represents movement in the front-back direction.

- **Z-axis** – Represents movement in the up-down direction.

Each position in space is defined using a set of three numerical values (**X, Y, Z**), where:

- **X** determines the horizontal position.
- **Y** determines the depth or forward-backward position.
- **Z** determines the vertical position.

By combining these values, a robot can be precisely positioned anywhere within its workspace. In the **2D Cartesian system**, only two axes (**X and Y**) are used to define a point on a flat surface. For example, a point at (3, 4) means:

- Move **3 units right** along the X-axis.
- Move **4 units up** along the Y-axis.

In the **3D Cartesian system**, a third axis (**Z**) is added to define height. A point (3, 4, 5) means:

- Move **3 units right** along the X-axis.
- Move **4 units forward** along the Y-axis.
- Move **5 units up** along the Z-axis.

This three-dimensional system is essential in robotics for precise movement and positioning.

Application in Robotics

The Cartesian coordinate system is widely used in robotic applications that require **straight-line movements** and **high precision**. Some examples include:

Industrial Robots

- Robotic arms used in **car assembly lines** move along X, Y, and Z axes to perform welding, painting, and assembling parts.
- Pick-and-place robots use Cartesian coordinates to pick objects from one position and place them in another.

CNC Machines

- Computer Numerical Control (CNC) machines use Cartesian coordinates to guide cutting tools in **precise straight-line movements** to create parts from metal, wood, or plastic.

3D Printers

- 3D printers use the **X and Y** axes to move the nozzle and the **Z-axis** to control the height of each printed layer. This allows for **precise layer-by-layer printing** to create complex objects.

Medical Robots

- **Surgical robots** use Cartesian coordinates for **precise incisions** and controlled movements during delicate procedures.

Automated Warehouses

- Robots in warehouses use **Cartesian movement** to navigate between shelves and retrieve items.

Advantages of the Cartesian Coordinate System in Robotics

- ✓ **High Precision** – Provides accurate movement in straight lines, making it ideal for tasks requiring accuracy.
- ✓ **Simple Programming** – Movement instructions are straightforward since the robot moves in well-defined X, Y, and Z directions.
- ✓ **Easy Control** – Robot motion can be controlled with simple numerical inputs.
- ✓ **Predictable Motion** – The robot's movement follows a structured path, reducing errors and improving efficiency.

Disadvantages of the Cartesian coordinate system

- ✗ **Limited Flexibility** – The system is not ideal for rotational or curved movements.
- ✗ **Larger Workspaces Needed** – Cartesian robots require **more space** than other types of robots, like those using cylindrical or polar coordinates.
- ✗ **Complex Mechanical Design** – Some robots, like robotic arms, require **complex joint systems** to follow Cartesian motion.

2. Polar Coordinate System

The **Polar Coordinate System** is an alternative way to define a position in space using:

1. **Radius (r)** – The distance from a fixed central point (origin).
2. **Angle (θ)** – The direction or angle measured from a reference axis (usually the positive X-axis).

Instead of using X and Y coordinates like in the **Cartesian system**, the polar system describes a point using **(r, θ)**, meaning:

- **r** determines how far the point is from the origin.
- **θ** determines the angle at which the point is located from a reference direction.

This system is useful for movements that involve **rotation, circular motion, or radial symmetry**.

Understanding Polar Coordinates

In a **2D polar system**, a point's position is defined by two values **(r, θ)**:

- The **radius (r)** represents the straight-line distance from the center (origin) to the point.
- The **angle (θ)** is measured in degrees or radians counter clockwise from the positive X-axis.

For example, a point at **(5, 45°)** means:

- Move **5 units away** from the origin.
- The direction is **45° from the positive X-axis**.

In a **3D polar system**, a third value (**φ**) is introduced:

- **r** (radius) – Distance from the origin.
- **θ** (azimuth angle) – Rotation around the Z-axis.
- **φ** (elevation angle) – Angle above or below the XY-plane.

This system is useful for defining spherical motion and robotic arms with rotational joints.

Application in Robotics

The Polar Coordinate System is widely used in robots that require **rotational and radial movements**. Some examples include:

1. Robotic Arms and SCARA Robots

- Many robotic arms operate using **rotational joints**. The polar system helps define their movements efficiently.
- **SCARA (Selective Compliance Articulated Robot Arm) robots** use polar coordinates for **circular motion**, commonly used in assembly lines.



2. Robotic Cameras and Radar Systems

- **Surveillance cameras** that rotate to scan an area use polar coordinates to determine their position.
- **Radar systems** use polar coordinates to track moving objects based on their distance and angle from the radar source.



3. Autonomous Vehicles and Drones

- **Drones and robotic vehicles** use polar coordinates for navigation, especially when tracking distances from a central point.
- **Mars Rovers and Space Robots** use polar coordinates



for analysing terrain and mapping.

4. Industrial Robots in Circular Workspaces

- Some **welding robots and robotic arms** work in **circular workspaces**, making the polar coordinate system more efficient than the Cartesian system.



Advantages of the Polar Coordinate System in Robotics

- ✓ **Efficient for Rotational Movements:** Ideal for robots that need to rotate around a fixed point.
- ✓ **Better Use of Space:** Reduces the need for large workspaces by allowing compact circular motion.
- ✓ **Faster Calculations for Circular Motion:** Simplifies computations for robots moving in arcs or circles.
- ✓ **Useful for Tracking and Sensing:** Helps in radar systems, robotic vision, and object tracking.

Disadvantages of the Polar Coordinate System

- ✗ **Less Accurate for Linear Motion** – Cartesian coordinates are better for straight-line movement.

✘ **Complex Calculations** – Converting between Cartesian and Polar coordinates requires additional computation.

✘ **Limited Use in Industrial Applications** – Many industrial robots still rely on Cartesian systems for precise straight-line motion.

3. Cylindrical Coordinate System:

The **Cylindrical Coordinate System** is a combination of both **Cartesian** and **Polar Coordinate Systems**. It is used to describe a position in **three-dimensional space** using:

1. **Radius (r)** – Distance from the central vertical axis (similar to polar coordinates).
2. **Angle (θ)** – The rotational position around the central axis (similar to polar coordinates).
3. **Height (Z)** – The vertical position from a reference plane (similar to Cartesian coordinates).

Instead of defining a position using **(X, Y, Z)** like in the **Cartesian system**, the cylindrical system describes a point as **(r, θ , Z)**, meaning:

- **r** (radius) determines how far the point is from the center.
- **θ** (angle) determines the rotational position around the center.
- **Z** (height) determines the vertical position.

This system is particularly useful for robotic systems that require **circular and linear movements together**.

Understanding Cylindrical Coordinates

In a **2D system**, only **r and θ** are used (like the Polar Coordinate System). However, in a **3D Cylindrical System**, a third coordinate **Z** is added for vertical movement.

For example, a point at **(5, 45°, 10)** means:

- Move **5 units away** from the central axis (r).
- Rotate **45° counter clockwise** from the reference direction (θ).
- Move **10 units up** in height (Z).

The Cylindrical System is ideal for robots that need to move up and down while also rotating around a central point.

Application in Robotics

The Cylindrical Coordinate System is widely used in robots that require a **combination of rotation and vertical movement**. Some examples include:

1. Industrial Robotic Arms

- Many robotic arms, such as those used in **automated assembly lines**, follow cylindrical motion to move **up/down and rotate** around a central base.

2. Warehouse and Storage Robots

- **Automated storage systems** use cylindrical motion to lift and rotate items stored on shelves.
- Some **warehouse robots** retrieve items by **rotating to the correct shelf, extending an arm, and lifting the item**.

3. Automated Drilling and Welding Robots

- **Drilling robots** use cylindrical motion to **rotate, position, and drill holes** in materials.
- **Welding robots** move **up and down** while rotating to weld pipes and cylindrical structures.

4. Surveillance and Security Robots

- Some **robotic cameras** use cylindrical motion to **pan and tilt** while adjusting height.
- **Radar systems** that track aircraft and ships often use cylindrical coordinates.

5. Medical and Surgical Robots

- Some **robotic surgical systems** use cylindrical motion for **precise rotation and vertical movement** in operations.

Advantages of the Cylindrical Coordinate System in Robotics

- ✓ **Ideal for Circular and Vertical Movements:** Perfect for robots that need to **rotate and move up/down**.
- ✓ **More Efficient Than Cartesian System:** Reduces unnecessary movements by allowing rotation instead of linear travel.
- ✓ **Useful for Space-Constrained Applications:** Compact robots in **factories, warehouses, and medical fields** benefit from this system.
- ✓ **Simplifies Robotic Arm Control:** Helps robotic arms perform **natural, efficient movements** in confined spaces.

Disadvantages of the Cylindrical Coordinate System

- ✗ **Less Suitable for Precise Straight-Line Motion** – Cartesian coordinates are better for straight-line movements.
- ✗ **More Complex Control Mechanism** – Requires additional programming for **rotational and height-based movements**.
- ✗ **Limited Flexibility in Some Applications** – Cannot handle complex **free-form** movements like Cartesian robots.

Comparison with Other Coordinate Systems

Feature	Cartesian Coordinate System	Polar Coordinate System	Cylindrical Coordinate System
Movement Type	Straight-line (X, Y, Z)	Circular (r, θ)	Rotational + Vertical (r, θ , Z)
Best For	Industrial robots, CNC, 3D printing	Rotating robots, robotic cameras	Warehouse robots, robotic arms
Accuracy	Very High	Moderate	High
Space Efficiency	Requires more space	More compact	Moderate

Chapter Highlights

- **Coordinate systems** help robots understand and control their position and movement in space.
- The **three main coordinate systems** used in robotics are:
 - i. **Cartesian**
 - ii. **Polar**
 - iii. **Cylindrical**
- **Cartesian coordinate system** uses **X, Y, and Z axes** for precise straight-line movement.
 - Used in CNC machines, 3D printers, robotic arms.
 - Advantage: High precision and easy control.
 - Limitation: Requires more space, not ideal for rotation.
- **Polar Coordinate System** uses **radius (r)** and **angle (θ)** to define positions in circular motion.
 - Used in SCARA robots, radars, rotating cameras.
 - Advantage: Efficient for rotation.
 - Limitation: Complex linear calculations.

Exercise

Multiple-Choice Questions (MCQs)

1. Which coordinate system uses X, Y, and Z axes to define position?
 - a) Polar
 - b) Cylindrical
 - c) Cartesian
 - d) Spherical
2. In a polar coordinate system, a point is represented by:
 - a) (X, Y, Z)
 - b) (r, θ)
 - c) (r, θ , Z)
 - d) (θ , ϕ)
3. Which system is most suitable for rotational and vertical motion?
 - a) Cartesian
 - b) Polar
 - c) Cylindrical
 - d) Spherical
4. What does 'Z' represent in the Cartesian coordinate system?
 - a) Forward-backward motion
 - b) Side-to-side motion

- c) Height or up-down motion
 - d) Rotational motion
5. Which coordinate system is used in CNC machines and 3D printers?
 - a) Polar
 - b) Cylindrical
 - c) Cartesian
 - d) Spherical
 6. What is the main limitation of the polar coordinate system?
 - a) Too precise
 - b) Not suitable for rotations
 - c) Complex linear motion calculations
 - d) Cannot be converted to Cartesian
 7. A SCARA robot best works using which coordinate system?
 - a) Cartesian
 - b) Polar
 - c) Cylindrical
 - d) Spherical
 8. Which coordinate system is best suited for circular workspace applications?
 - a) Cartesian
 - b) Polar
 - c) Cylindrical
 - d) Hexagonal
 9. What does the radius (r) in polar and cylindrical systems define?
 - a) Rotation speed
 - b) Height
 - c) Distance from the center
 - d) Distance from Z-axis
 10. Which system allows movement in arcs and circular patterns more easily?
 - a) Cartesian
 - b) Polar
 - c) Hexagonal
 - d) Parallel

True/False

1. Cartesian coordinate system defines location using X, Y, and Z.
2. Cylindrical coordinate system uses (r, θ) only.
3. Polar coordinates are useful for circular and rotational movement.
4. Cartesian systems are better for circular movements than polar systems.
5. SCARA robots usually operate using polar coordinates.

Fill in the Blanks

1. Cartesian coordinates use _____ to define positions.
2. In polar coordinates, a point is defined using _____ and _____.
3. _____ coordinate system combines polar and Cartesian features.
4. CNC machines commonly use _____ coordinate systems.
5. The height in a cylindrical coordinate system is represented by _____.

Assertion and Reason

- Assertion (A):** Cartesian coordinates are ideal for precise straight-line motion.
Reason (R): They use perpendicular axes for movement.
 - Both A and R are true, and R is the correct explanation.
 - Both A and R are true, but R is not the correct explanation.
 - A is true, R is false.
 - A is false, R is true.
- Assertion (A):** Polar coordinate system is not suited for linear motion.
Reason (R): It defines position using X, Y, and Z values.
 - Both A and R are true, and R is the correct explanation.
 - Both A and R are true, but R is not the correct explanation.
 - A is true, R is false.
 - A is false, R is true.
- Assertion (A):** Cylindrical systems are efficient for vertical and circular movement.
Reason (R): They use radius, angle, and height to define position.
 - Both A and R are true, and R is the correct explanation.
 - Both A and R are true, but R is not the correct explanation.
 - A is true, R is false.
 - A is false, R is true.
- Assertion (A):** Cartesian coordinate system requires complex angle calculations.
Reason (R): It is based on angular distance from the origin.
 - Both A and R are true, and R is the correct explanation.
 - Both A and R are true, but R is not the correct explanation.
 - A is true, R is false.
 - A is false, R is true.
- Assertion (A):** Robots in circular workspaces often use polar coordinate systems.
Reason (R): Polar systems are best for defining radial positions.
 - Both A and R are true, and R is the correct explanation.
 - Both A and R are true, but R is not the correct explanation.
 - A is true, R is false.
 - A is false, R is true.

Short Type Questions

- What are the main components of the Cartesian coordinate system?
- Give two applications of polar coordinate systems in robotics.
- How does the cylindrical system combine features of Cartesian and polar systems?
- Mention one advantage and one limitation of the Cartesian coordinate system.
- Explain the use of the Z-axis in cylindrical and Cartesian coordinate systems.

Long Type Questions

- Describe the Cartesian coordinate system and explain its applications in robotics.
- Compare and contrast the polar and cylindrical coordinate systems with examples.
- Explain how coordinate systems help robots navigate and perform tasks.

4. What are the advantages and disadvantages of using the Cartesian system in industrial robots?
5. Illustrate the differences between Cartesian, Polar, and Cylindrical coordinate systems in a tabular form with suitable examples.