Chapter (1): Introduction

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* **Robotics:** The study of machines that can replace human beings in the execution of a task in terms of physical activity & decision making.

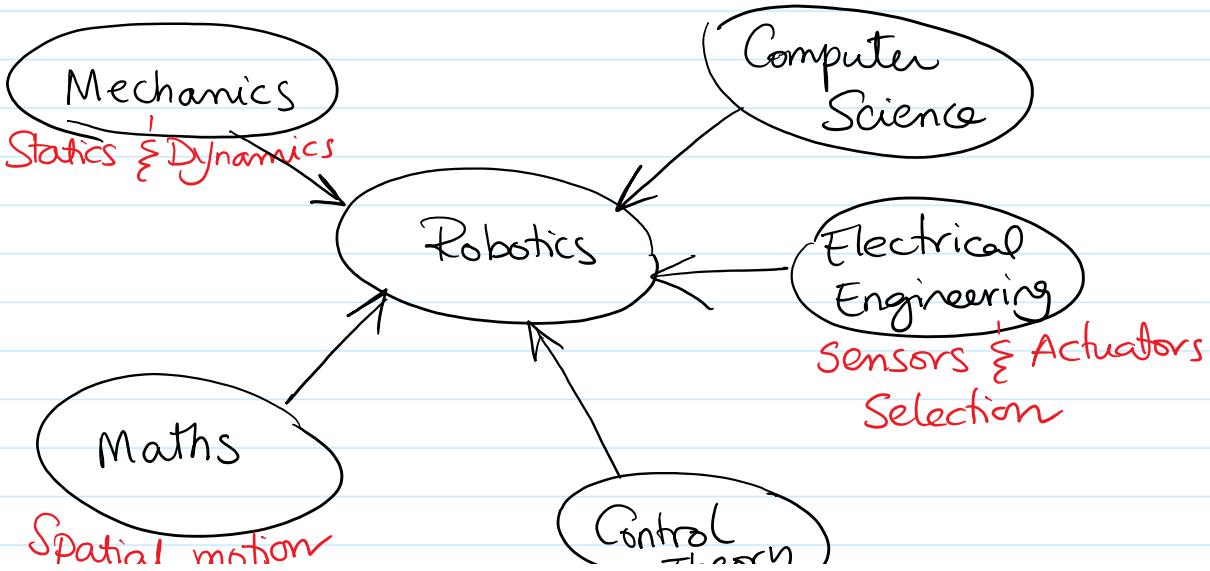
* **Robot:** a goal oriented machine that can sense, plan, and act.

* If it is Dull, Dirty, or Dangerous, it's a robot's job
  - Dull → repetitive tasks (factories)
  - Dirty → sewage systems
  - Dangerous → nuclear plants, space, oceans...

The study of robotics is based on 3 fundamental laws:

1) A robot may not injure a human being, or allow a human being to come to harm.
2) A robot must obey the orders given by humans except when they conflict with the first law.
3) A robot must protect its own existence as long as this does not conflict with the first & second laws.

The study of the mechanics & Control of manipulators is a collection of classical topics:



Spatial motion description

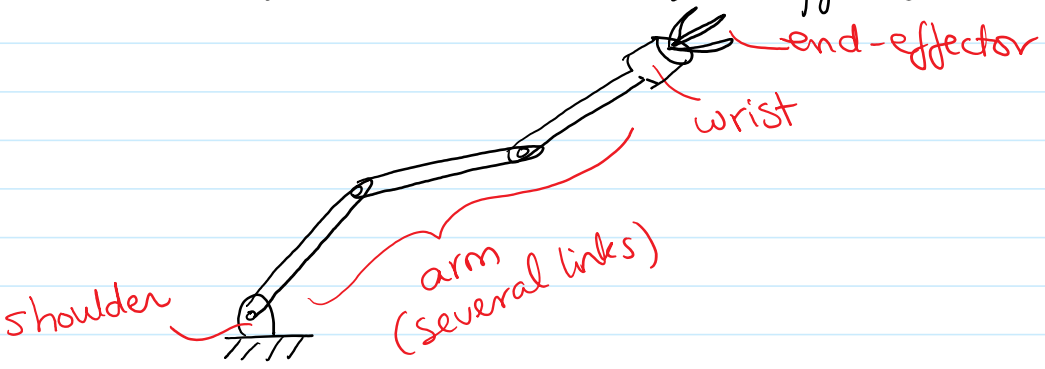
Control Theory

Classifications of Robots

- Robot Manipulators (Fixed base)
- Mobile Robot (Mobile base)

Robot Manipulators:

Manipulator: Sequence of (rigid) links connected by joints that allow relative motion of neighbouring links. It is characterized by a shoulder, an arm, a wrist and an end-effector

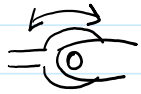
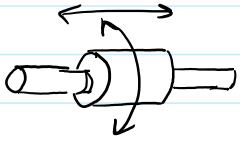
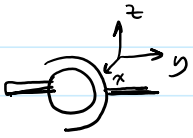


(Serial (open) kinematic chain)
↳ one sequence of links connecting the 2 ends of the chain.

Link: rigid sections that make up the mechanism

Joint: connection between 2 links, ensuring the mobility of the manipulator. They allow restricted relative motion between the neighbouring links.

Types of joints:

Joint	Representation	Description	DOF
1) Revolute		Allows relative rotation about 1 axis	1
2) Prismatic		Allows relative translation about 1 axis	1
3) Cylindrical		Allows relative translation & Rotation about 1 axis	2
4) Spherical		Allows relative rotation about three axes	3
5) Planar		Allows relative translation on a plane (2 directions) & rotation about an axis perpendicular to the plane.	3

Degrees of Freedom: # of independent variables that need to be specified to fully describe the motion of an object.

$$DOF = \lambda(n-1) - \sum_{i=1}^{K} (\lambda - f_i)$$

n: # of links including ground
K: # of joints
f_i: # of DOF for joint i
λ: 3 (planar) / 6 (spatial)

Usually 6 DOF in a 3D Space:
1) 3 for positioning a point on the object
2) 3 for orienting the object wrt a reference coordinate frame.

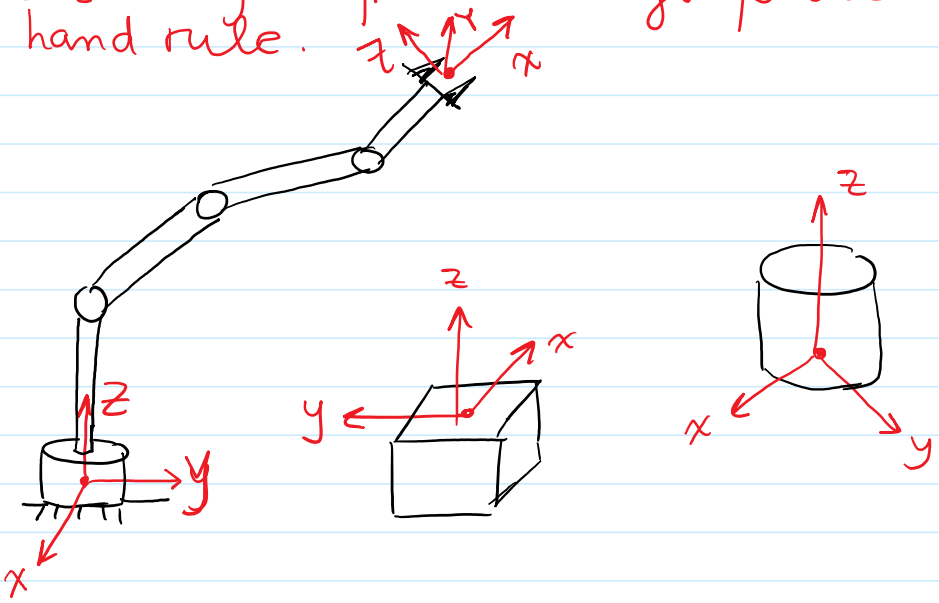
Work Space: portion of the environment that the manipulator's end-effector can access. Its shape & volume depend on the manipulator's structure & joint limits.

Description of Position & Orientation

We need to attach a coordinate system (frame) rigidly to the object.

Then describe the position & orientation of this frame wrt a reference frame.

* Make sure your frame always follows the right hand rule.



All these frames are different from the ref. frame XYZ in position and orientation.

* In Chapter 2 we will learn how to express the position & orientation of one frame wrt the reference frame.

Forward Kinematics

Kinematics is the science of motion that treats motion without regard to the forces which cause it. (position, velocity, acceleration)

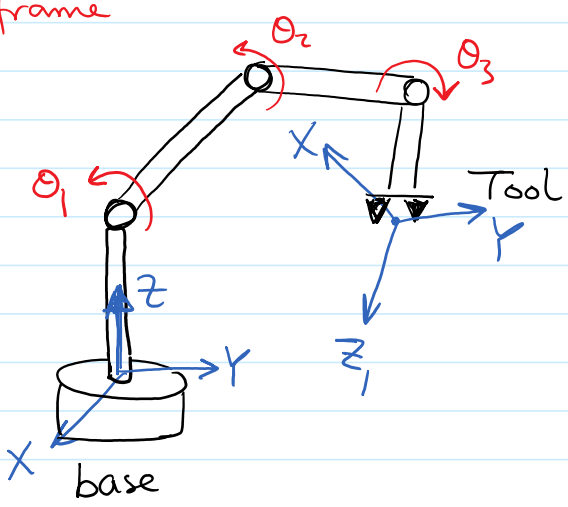
* Usually we describe the the position & orientation of the tool frame (end-effector frame) with respect to

The base frame.

Forward Kinematics: Computing the position & orientation of the end effector given a set of joint angles with respect to the base frame

Note: FK is a transformation of the joint space to Cartesian space

- joint space → $\theta_1, \theta_2, \theta_3, \ldots$ of the joints at an instant
- Cartesian space → position & orientation of the tool frame wrt the base frame



* FK problem has only one solution *

Inverse Kinematics: Computing all possible sets of joint angles that could be used to attain a specific position & orientation.

* This problem is more complicated than the FK problem. The equations are non-linear → solutions are difficult.

→ Multiple Solutions are possible
→ No solution sometimes happens ⇒ Desired point is outside the workspace of the manipulator.

Velocities, Singularities & Static Forces

Jacobian Matrix: A matrix that maps velocities in the joint space to velocities in the Cartesian Space.

Singularity: The case where the Jacobian matrix is not invertible → Physically, this causes problems with the motions of arms.

Static forces problem: Knowing the static force that needs to be applied by the manipulator → the joint torques are calculated.

Dynamics: Studying the forces required to cause motion (This helps in Simulating the motion of the robot)

Trajectory Generation: Specify a path that the end-effector should follow, and thus calculating the joint motions required to achieve such a path.

* Notations

1) Variables in upper case are vectors: $R, B, A, \ldots$
   Variables in lower case are scalars: $k, a, c \ldots$

2) Leading superscript for a vector → Coordinate system This vector is described in: ${}^{A}P$: vector P in the CS $\{A\}$

   Leading subscripts & Superscripts for a matrix → This matrix provides a relationship between those 2 CS
   ${}^{A}_{B}R$: Describes frame $\{B\}$ in the CS $\{A\}$

3) Trailing superscripts ⇒ Inverse or Transpose

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R^T , R^{-1}

4) Trailing subscripts may indicate a vector component P_x, P_y, P_z or may be used as a description P_{bolt}, P_1 ...

5) $\cos\theta_1 = C\theta_1 = c_1$

$\sin\theta_1 = S\theta_1 = S_1$.

* The position of a Point in space is described with a position vector P

* Orientation of a body will be described with an attached coordinate system.