0. Introduction

* A device that automa
certain, often repetit

B This course covers two fundamental aspects of robotics:

a) Manipulators

b) Mobile robotics

* But not how to make a robot

C. Manipulators Section

* Spatial representations and transformations
* Forward kinematics
* Inverse kinematics
* Jacobians
* Motion planning & control

Jacobian links velocit
to that of links ↔

D. Assessment

a) Manipulators assignments (25%)

c) Exam (50%)

⇨ Learning Outcomes

LO1) Develop and apply forward kinematics to obtain the end-effector position and orientation in the base coordinate frame as a function of the joint parameters

LO2) Apply inverse kinematics to calculate all possible sets of joint parameters that result in a given end-effector position and orientation relative to the base coordinate frame

LO3) Construct the Jacobian matrix for an articulated manipulator and use it to calculate static forces and torques, and derive dynamic equations for each link

LO4) Apply simple, linear interpolative path planning techniques to control end-effector motion for an articulated manipulator

tically performs
ive tasks

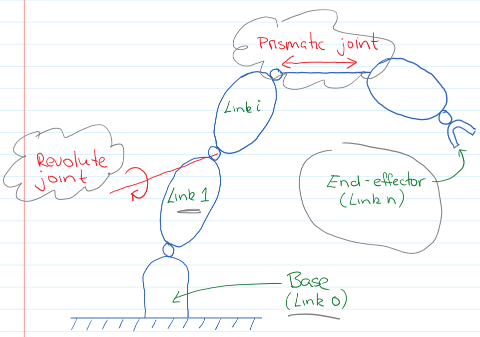
s of joints
torques/ forces

1. Spatial Representations

<Hotwire>

A. Describing a manipulator

We have a manipulator - series of links + joints



Spherical joint = 3 re... with ... betwe...

Links : n moving links (1, 2 ... n)
1 fixed link (base)

Joints : Revolute ___1___
Prismatic ___1___ } DOF ?

Q What is the ultimate goal of a manipulator such as this?? (In the simplest sense)

To get the end-effector to a known position & orientation

To do this, we need to be able to describe the end-effector position and orientation...

How?? - That's what this first topic covers...

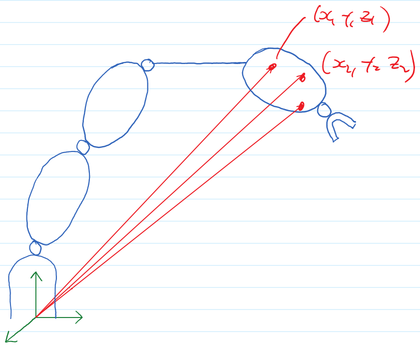
✱ Configuration parameters : A set of ~~position~~ parameters that describes the full configuration of the system

If we take one of these links, how can we fully describe its:

Q ✱ Position ? - cartesian, polar coords

Q ✱ Orientation? roll-pitch-yaw, rotation matrices quaternions

How about a free object in space?



Q How many parameters?

joints
no distance
een

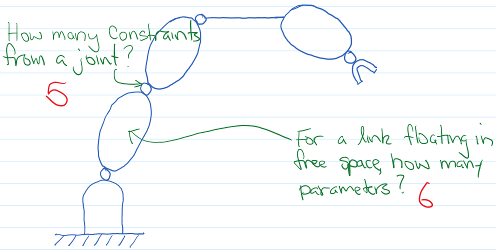
Q How many parameters?

3? 6? 9? —

Q How many independent parameters?

6 — 3 position, 3 rotation

* **Generalised Coordinates**: A set of independent configuration parameters



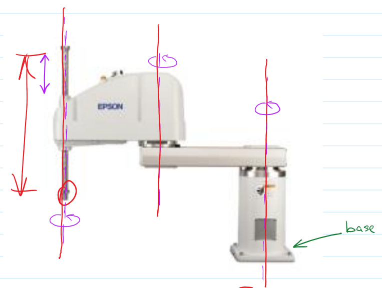
n moving links = $6n$ parameters — if in free-space

n 1 DOF joints = $5n$ constraints

Q $\Rightarrow$ DOF_{system} = $6n - 5n = n$

= * Generalised coords for system

* **Degrees of freedom**: Number of generalised coordinates



Epson 4DOF

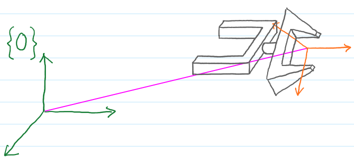
UR5

6DOF

* How many DOF for this SCARA robot?

The end effector is the business-end of the robot. So we want to consider how we can represent its position and orientation

- End effector config parameters
- $\{x_1, x_2 \ldots x_{m_0}\}$: m_0 independent config parameters (generalised coords)



m_0: * DOF of end effector
- what is the maximum? 6

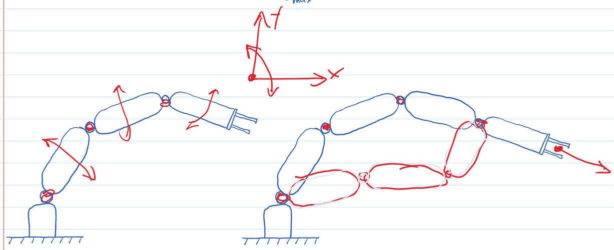
* If we want the end-effector to be able to reach any point in the workspace with any orientation

how many DOF do we need? 6

* If $n > m_o$, the robot is termed redundant

- The end effector can stay in a fixed pos + orient while the rest of the manipulator can vary

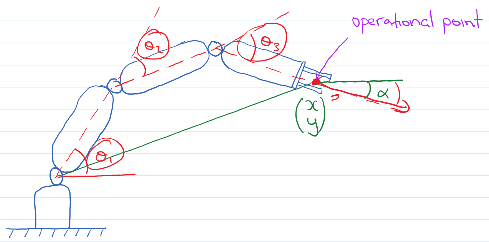
For a planar robot, how many DOF can the end effector have? ($m_{o_{max}}$)



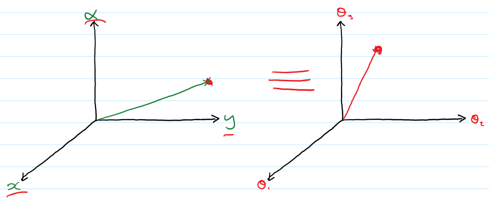
<Robai 7 dof>

⇒ There are a number of ways we can represent the configuration of the manipulator and end-effector

* Operational Coordinates → Operational space
* Joint Coordinates ⟶ Joint space / Config space



op point changes depending on what robot does
- grip
- weld



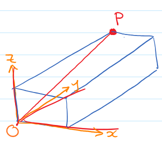
We need to be able to move between these:
We control in Config space
Obstacles / tasks in Operational space
} Kinematics

B. Frames

In operational space we use frames to describe the position and orientation of a rigid body (link)

1. We attach a Cartesian frame (axes) to the body

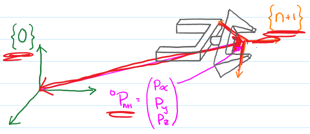
Any point on this body can now be describe by a vector in the attached frame



$$P = \vec{OP} = \begin{pmatrix} P_x \\ P_y \\ P_z \end{pmatrix}$$

II. We can describe the position and orientation of this body frame in another, reference frame

if we change the ref frame, we change the vector



$${}^0P_{n+1} = \begin{pmatrix} P_x \\ P_y \\ P_z \end{pmatrix}$$

→ Position is given by the vector, ${}^0P_{n+1}$, to the origin

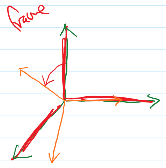
$${}^0P_{n+1}$$

Frame in which the vector is expressed

Frame whose origin is being described

$${}^0P_{n+1} \neq {}^{n+1}P_0$$

→ Orientation is given by describing the rotation of one frame w.r.t. another



Parent / ref frame

$${}^{0}_{n+1}R = [\quad] \leftarrow \text{Rotation matrix}$$

frame being described

* With these two components, we can transform the coordinates of any point on a rigid body to coordinates in a fixed reference frame

eg. The operational point of the end effector in the base frame of the robot

Summary:

* Manipulator = Links and Joints
  - Revolute
  - Prismatic

* Configuration parameters → Generalised coords
  - Constraints
  - DOF

* Operational space - End effector
  Joint space - Joint angles
  } kinematics.

* Frames