MTR08114 Robotics What Will We Do??!!

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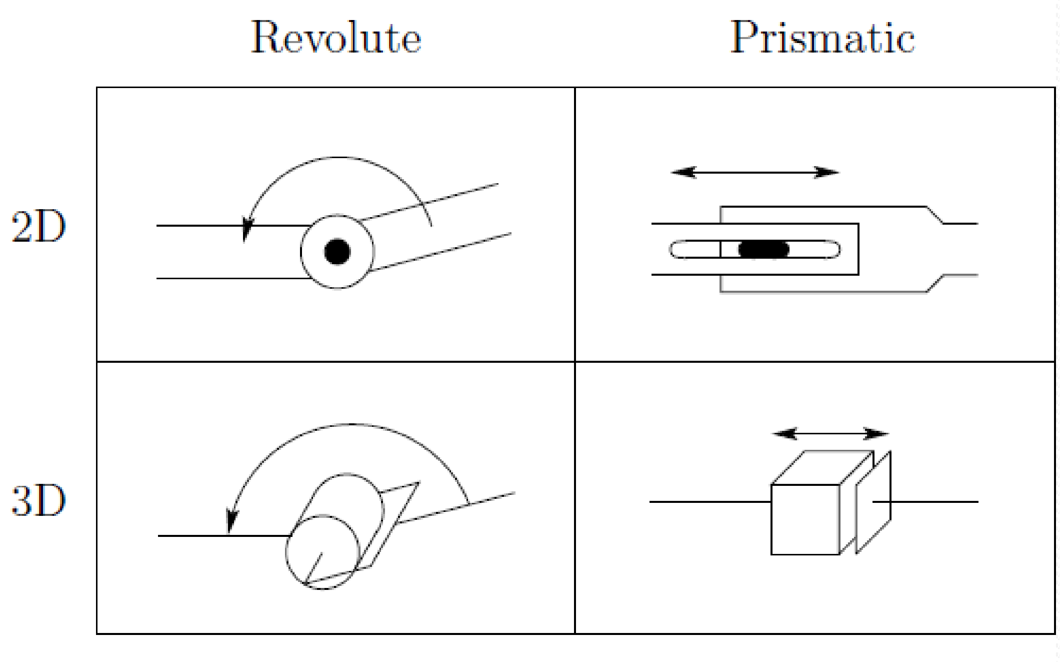
REMINDER 1: Definition

- Book: Computer Controlled Industrial Manipulator

- RIA: a reprogrammable multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.

REMINDER 2: Symbolic Representation

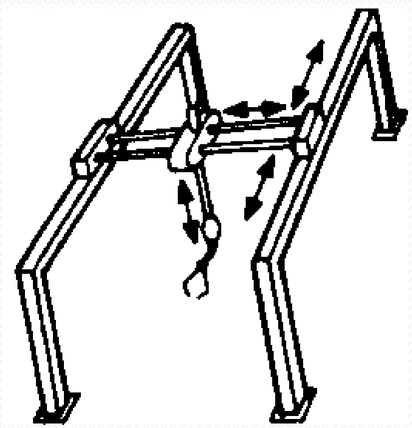
- Kinematic Chains = links+Joints



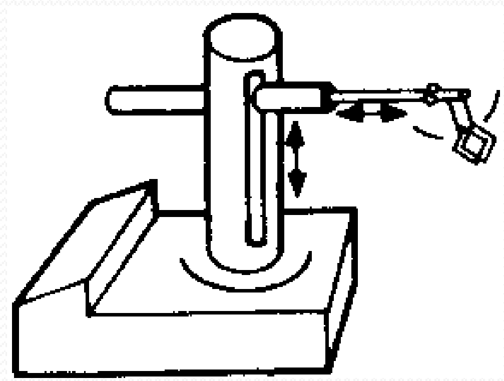
- Joint Angle (Revolute) = Θ
- Displacement (Prismatic) = d

REMINDER 3:Geometry (Examples)

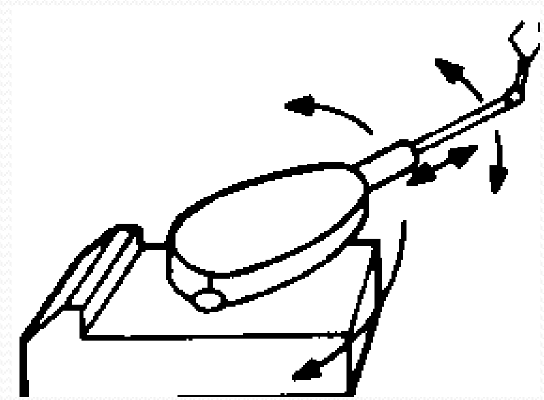
Cartesian



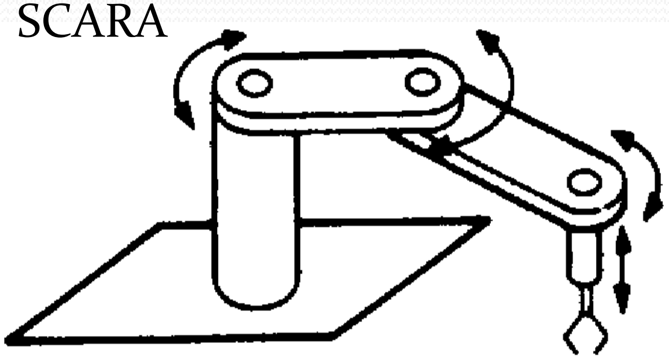
Cylindrical



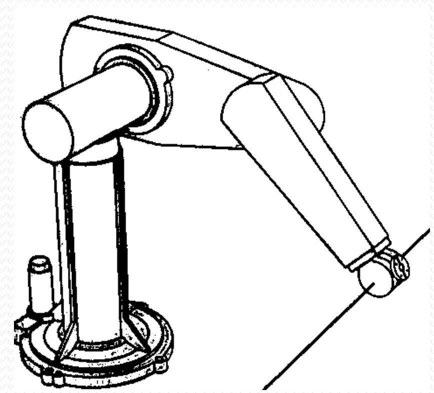
Spherical



SCARA



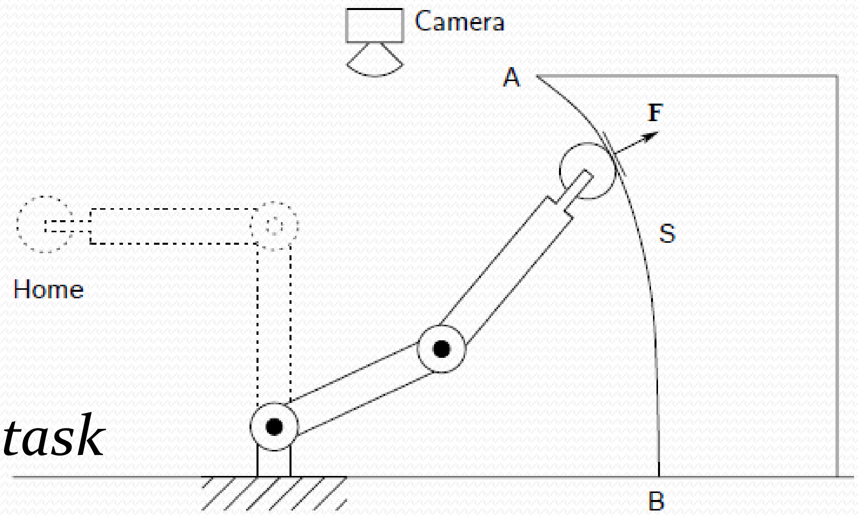
Articulated



Our goal

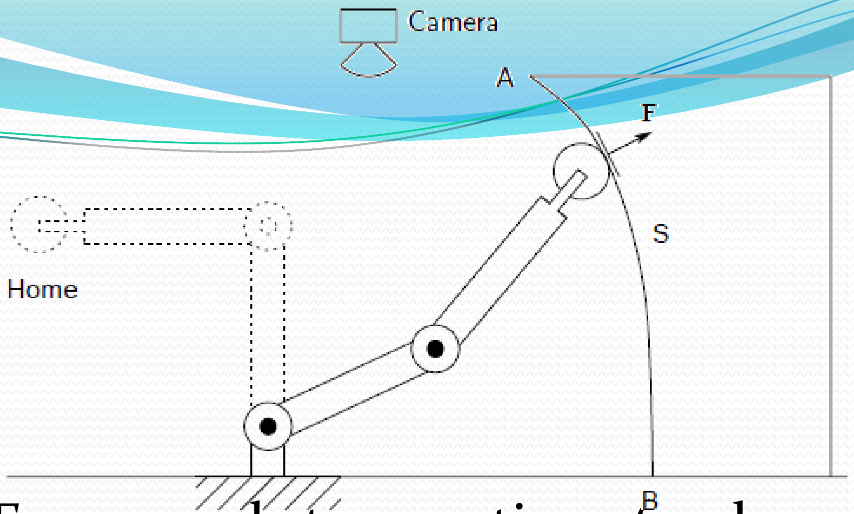
- Control almost ANY serial manipulator to move the end effector AS WE LIKE and touch things WHEN WE WANT with the force WE DECIDE while respecting all lows of physics!!!

- Example:
  - Make this robot follow the contour from A to B using constant given speed



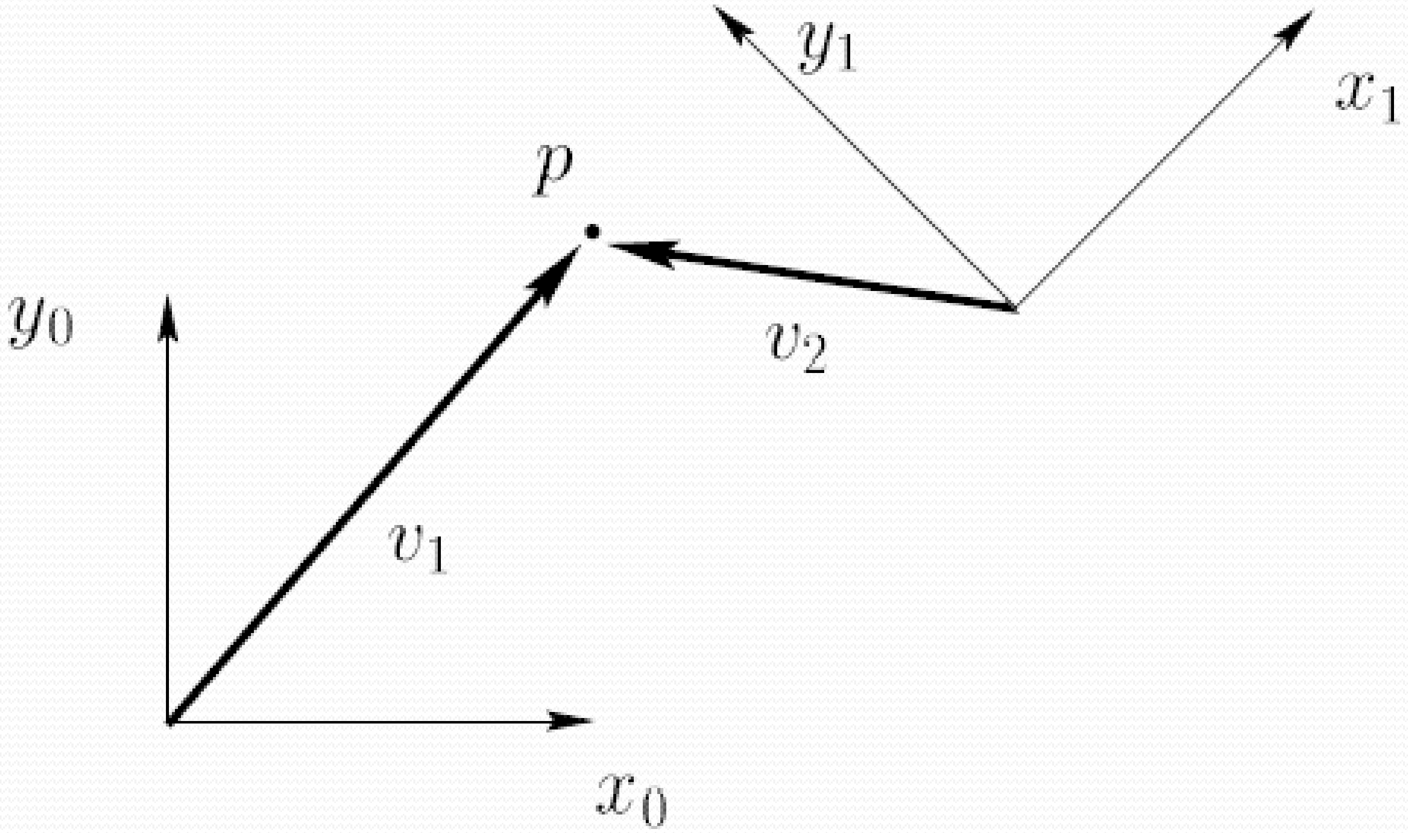
- In General: *this is not at all an easy task*

How To Do It

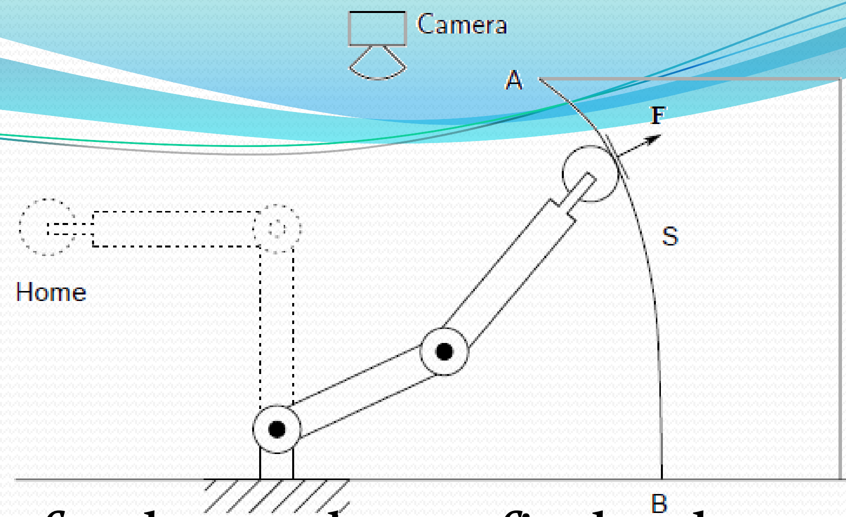


- Problem 1
  - Make our goal mathematical … From words to equations (and back!!)
  - This is called Representation and will be our first task
  - Examples:
    - How to represent all points of the robot as compactly as possible?
    - How to represent a rotation in space?
    - How can we move between different vintage points (reference frames)?
    - ……….

How To Do It - Representation



How To Do It

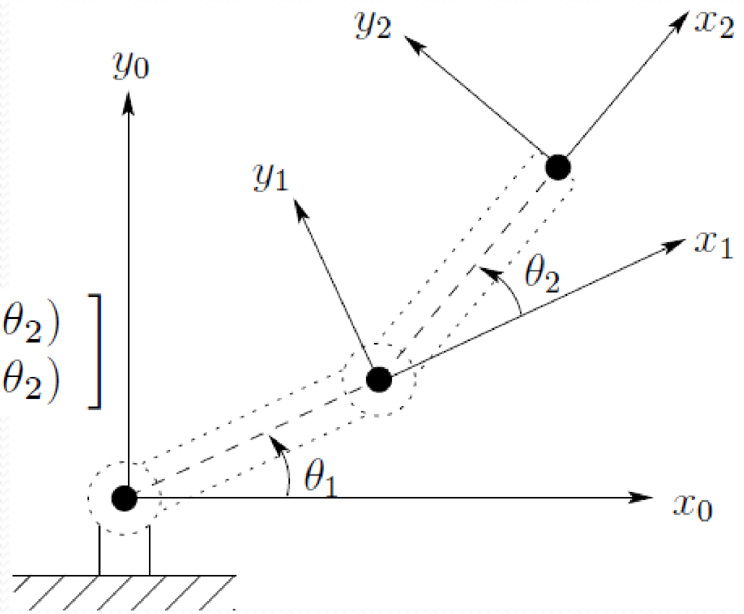


- Problem 2
  - Given the configuration of the robot, find the configuration of the end effector
  - This is called forward kinematics (our first task)
  - Examples:
    - Given a RR robot with angles Θ1 and Θ2 find the location and orientation of the end effector
    - Given a RRPRRPRPPPPRPRRRRPPPRPRPPPRPRPRPPPRRPRP manipulator, find the location and orientation of the end effector

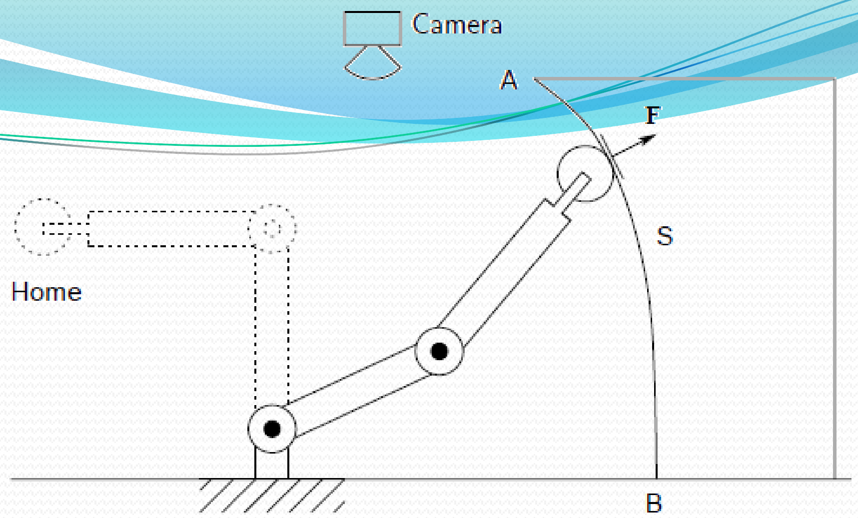
How To Do It – Forward Kinematics

$$
\begin{aligned}
x &= x_2 = \alpha_1 \cos\theta_1 + \alpha_2 \cos(\theta_1 + \theta_2) \\
y &= y_2 = \alpha_1 \sin\theta_1 + \alpha_2 \sin(\theta_1 + \theta_2)
\end{aligned}
$$

$$
\begin{bmatrix} x_2 \cdot x_0 & y_2 \cdot x_0 \\ x_2 \cdot y_0 & y_2 \cdot y_0 \end{bmatrix} = \begin{bmatrix} \cos(\theta_1 + \theta_2) & -\sin(\theta_1 + \theta_2) \\ \sin(\theta_1 + \theta_2) & \cos(\theta_1 + \theta_2) \end{bmatrix}
$$



- In general:
  - We use Denavit-Hartenberg convention for frame assignment
  - We use transformations between frames to get to the tool

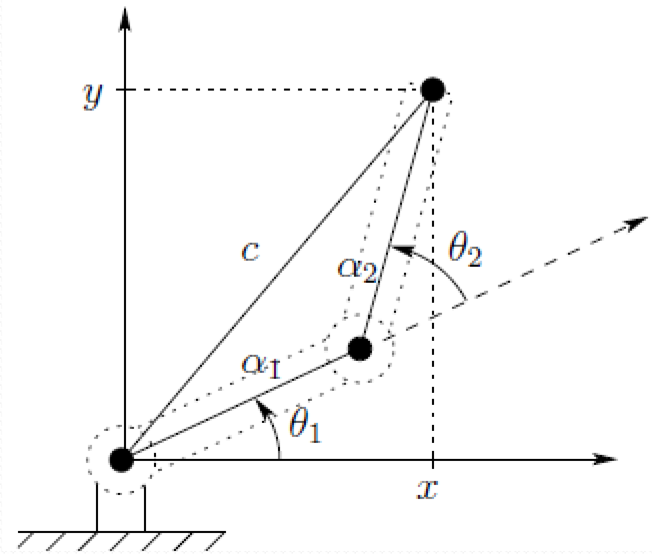


How To Do It

- Problem 3
  - Given a required configuration for the end effector, find the configuration of all joints in the robot.
  - This is called Inverse Kinematics
  - Examples:
    - How to make the end effector touch a box?
    - How to make the end effector reach a point?

How To Do It – Inverse Kinematics

- Two Solutions:
  - Elbow down
  - Elbow Up



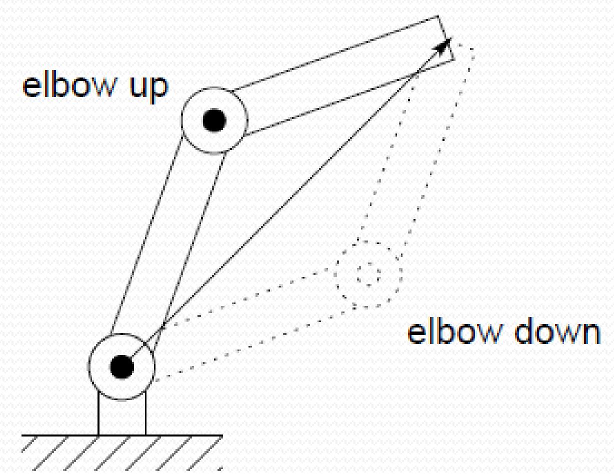
$$\cos\theta_2 = \frac{x^2 + y^2 - \alpha_1^2 - \alpha_2^2}{2\alpha_1\alpha_2} := D$$

$$\theta_2 = \cos^{-1}(D)$$

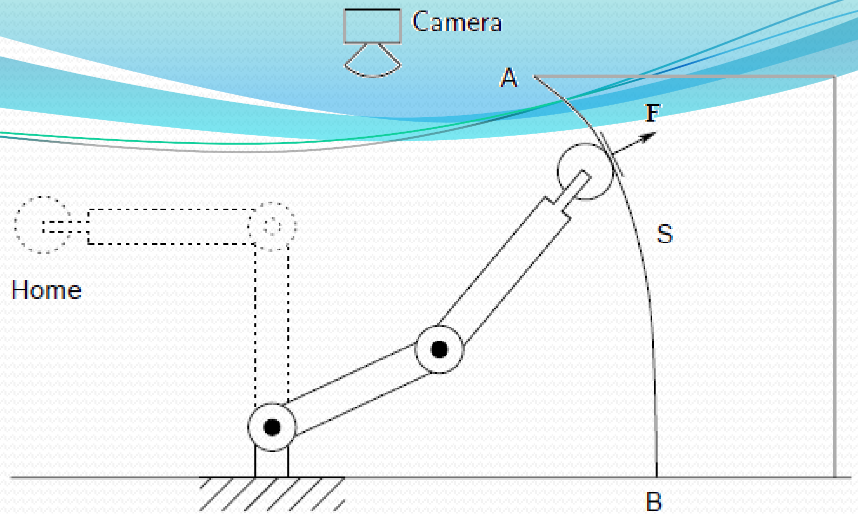
$$\sin(\theta_2) = \pm\sqrt{1 - D^2}$$

$$\theta_2 = \tan^{-1}\frac{\pm\sqrt{1 - D^2}}{D}$$

$$\theta_1 = \tan^{-1}(y/x) - \tan^{-1}\left(\frac{\alpha_2\sin\theta_2}{\alpha_1 + \alpha_2\cos\theta_2}\right)$$



How To Do It

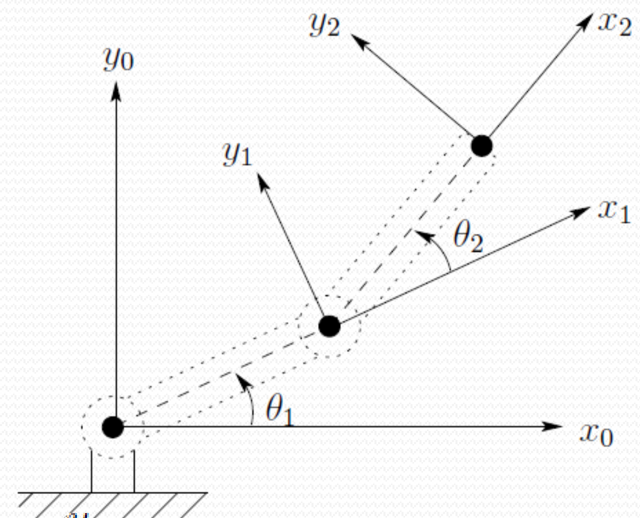


- Problem 4
  - How to follow the contour at a prespecified velocity?
  - This is called Velocity Kinematics
  - Example
    - Go from A to B in straight line at a speed of 50 m/hours

How To Do It – Velocity Kinematics

$$
\begin{aligned}
\dot{x} &= -\alpha_1 \sin\theta_1 \cdot \dot{\theta}_1 - \alpha_2 \sin(\theta_1+\theta_2)(\dot{\theta}_1+\dot{\theta}_2) \\
\dot{y} &= \alpha_1 \cos\theta_1 \cdot \dot{\theta}_1 + \alpha_2 \cos(\theta_1+\theta_2)(\dot{\theta}_1+\dot{\theta}_2)
\end{aligned}
$$

$$
\begin{aligned}
\dot{x} &= \begin{bmatrix} -\alpha_1 \sin\theta_1 - \alpha_2 \sin(\theta_1+\theta_2) & -\alpha_2 \sin(\theta_1+\theta_2) \\ \alpha_1 \cos\theta_1 + \alpha_2 \cos(\theta_1+\theta_2) & \alpha_2 \cos(\theta_1+\theta_2) \end{bmatrix} \dot{\theta} \\
&= J\dot{\theta}
\end{aligned}
$$

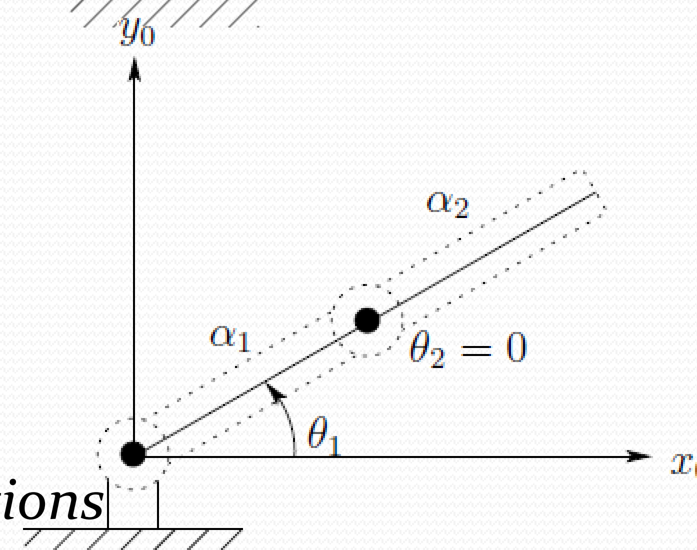


J is called the *Jacobian*

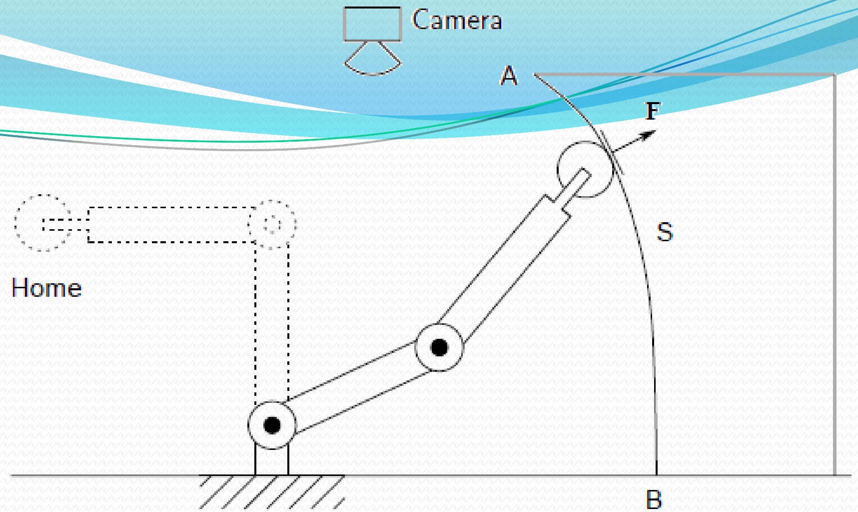
$$
\dot{\theta} = J^{-1}\dot{x}
$$

$$
J^{-1} = \frac{1}{\alpha_1\alpha_2 s_{\theta_2}} \begin{bmatrix} \alpha_2 c_{\theta_1+\theta_2} & \alpha_2 s_{\theta_1+\theta_2} \\ -\alpha_1 c_{\theta_1} - \alpha_2 c_{\theta_1+\theta_2} & -\alpha_1 s_{\theta_1} - \alpha_2 s_{\theta_1+\theta_2} \end{bmatrix}
$$

- *If The Jacobian has no inverse, then the configuration is singular which means that it cannot move in some directions*

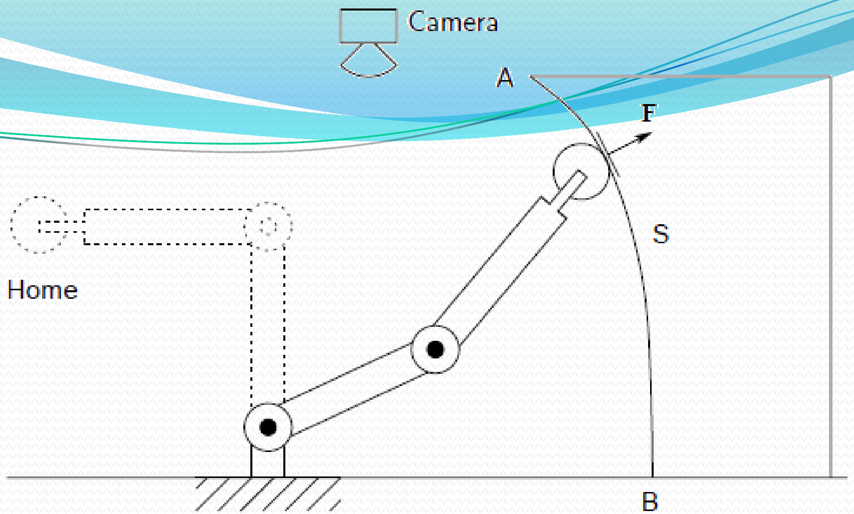


How To Do It



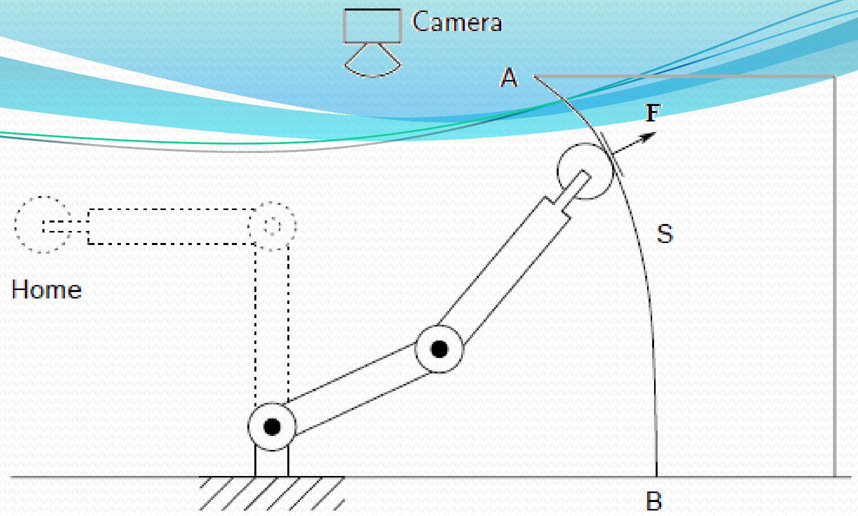
- Problem 5
  - How to control intermediate states while going from A to B?
  - This is called Trajectory Control
  - Has three stages:
    - Path Planning (no time consideration)
    - Trajectory Generation (with time consideration)
    - Trajectory Tracking (real time)

How To Do It

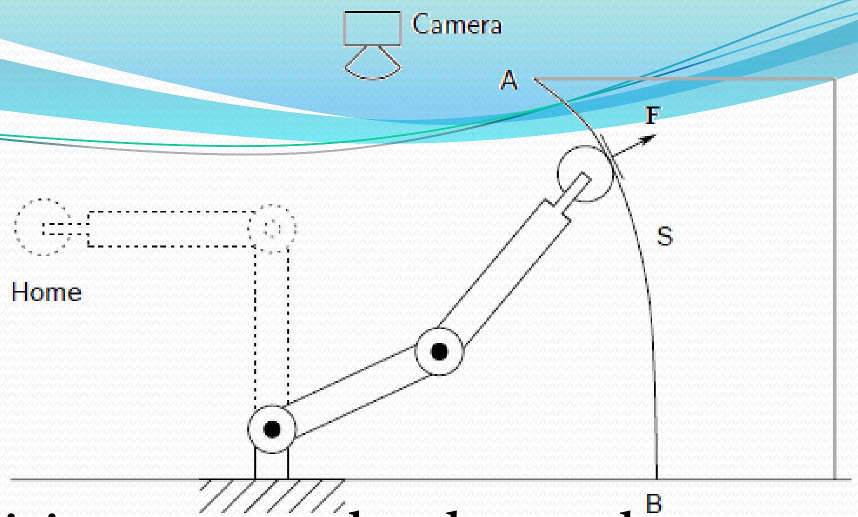


- Problem 6
  - How much torque we need for the actuators (motors) to generate the required motion?
  - This is called Dynamics
  - We use Lagragian Dynamics
  - Here we need to consider the actuators (motors) and power transmission

How To Do It



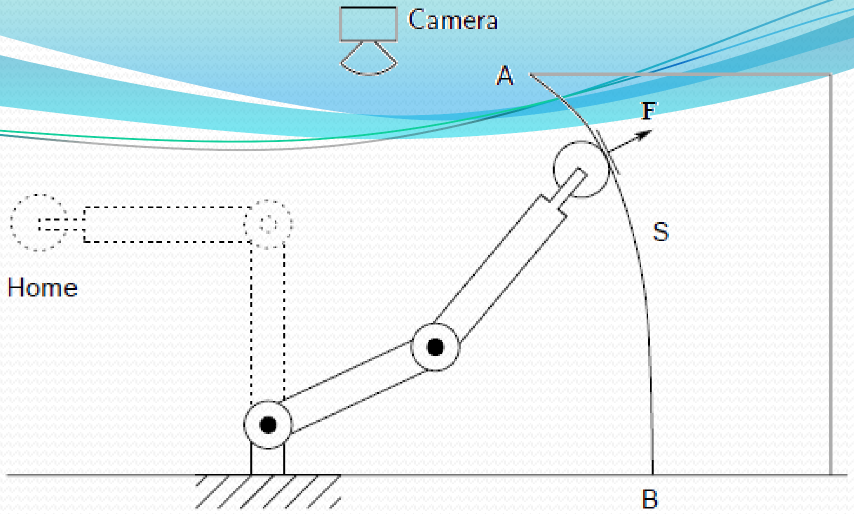
- Problem 7
  - How to generate the required commands (torques) online while rejecting disturbances?
  - This is called Position Control
  - This is a special case of general Automatic Control
  - In this course we will touch this but deep enough only to appreciate how deep is it



How To Do It

- Problem 8
  - Any small change in position may lead to huge differences in force, how to control the contact force to the surface from A to B?
  - This is called Force Control
  - This is a special case of general Automatic Control
  - In this course we will touch this but deep enough only to appreciate how deep is it

How To Do It



- Problem 9
  - How to utilize he Camera to correct for planned actions, avoid obstacles, etc?
  - This is called Vision
  - In this course we will touch this but deep enough only to appreciate how deep is it