One Day Workshop on Robotics and Automation

Dec. 30, 2011

Introduction to Mechanics in General Robotics

Presented by:

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Presentation Covers:

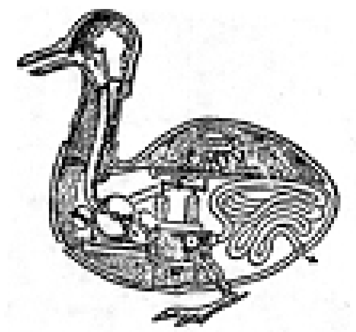
1. Brief Intro on Robotics
2. Introduction to Robot Dynamics
3. Introduction to Robot Kinematics
4. Introduction to Robot Statics
5. Manipulator Mechanism Design
6. Building a Robot

1. Brief Intro on Robotics

- There is no widely accepted definition of robot.

322 BC – Aristotle wrote "If every tool, when ordered, or even of its own accord, could do the work that befits it... then there would be no need either of apprentices for the master workers or of slaves for the lords."

In 1954, Devol filed a U.S. patent for a new machine for part transfer, and he claimed the basic concept of teaching/playback to control the device.
This scheme is now extensively used in most of today's industrial robots.

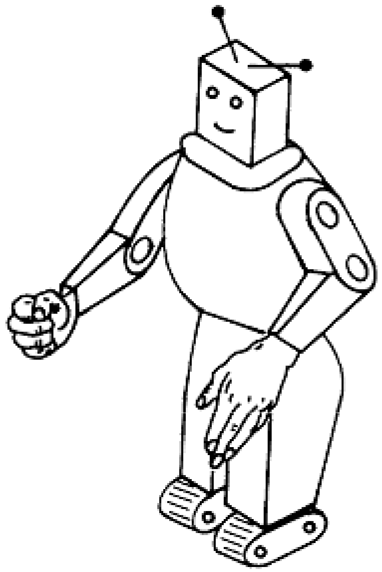


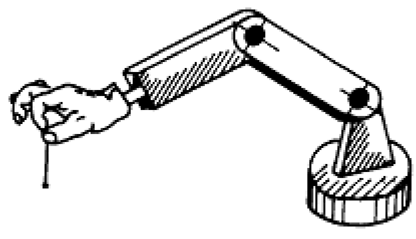
1738, Mechanical Duck, Jacques de Vaucanson

Early version of Mars Robot
Source: JPL

So what is a robot

- *Industrial robot*
- *Pick and place robot*
- *Manipulator*
- *Intelligent robot*
- *Fixed-stop robot*
- *Android*
- *Open loop robot*
- *Mobile robot*
- *Limited-degree-of-freedom robot*





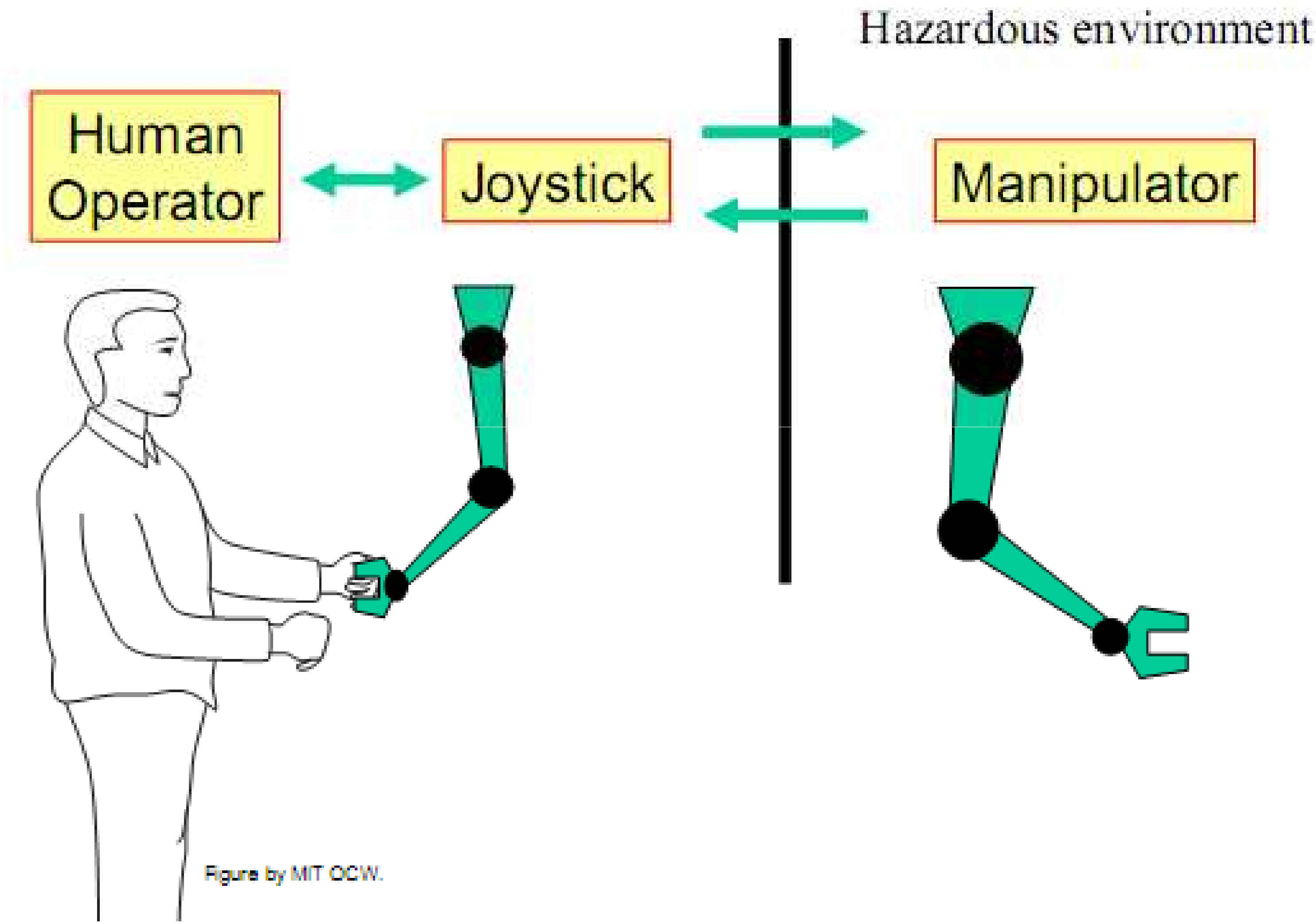

Hazardous environment
Human Operator
Joystick
Manipulator
Figure by MIT OCW.

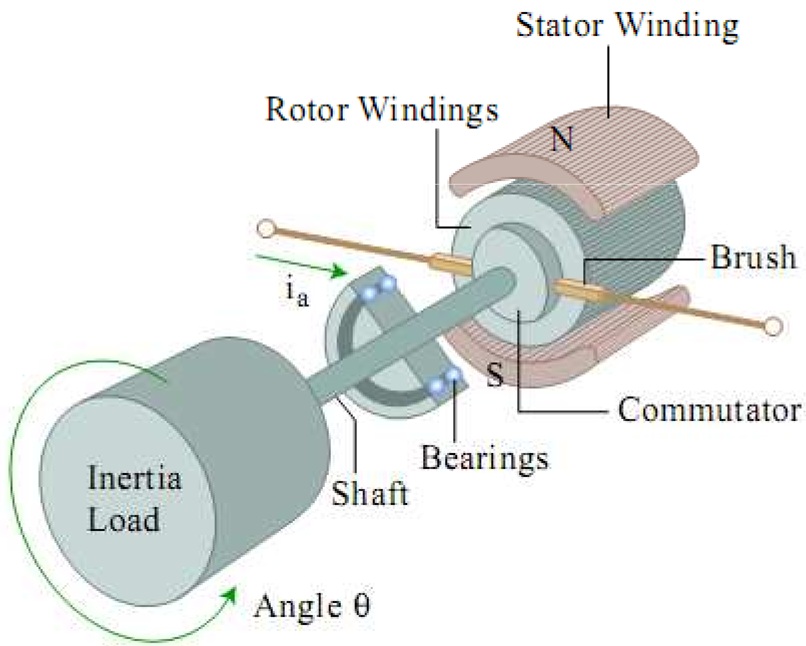
Image courtesy: RoboCup Nepal 2064

2. Introduction to Robot Dynamics

Actuators/Drive systems

- A robot has many degrees of freedom, each of which is a servoed joint generating desired motion.

- Electromagnetic Drive
    - AC motors
        - Standard voltage
        - cheaper
    - DC motors
        - Ease of speed control
    - Stepper motors
        - Accurate position and control
    - Solenoid drive

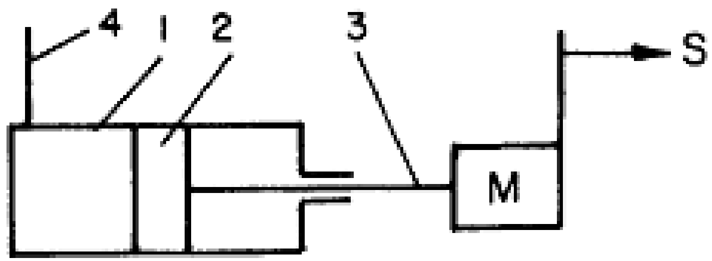


Construction of DC motors

Dynamics..

- Hydraulic drive

$$M\ddot{s}+(\mathrm{sgn}\,\dot{s})\psi\dot{s}^2 = pF-Q,$$



where

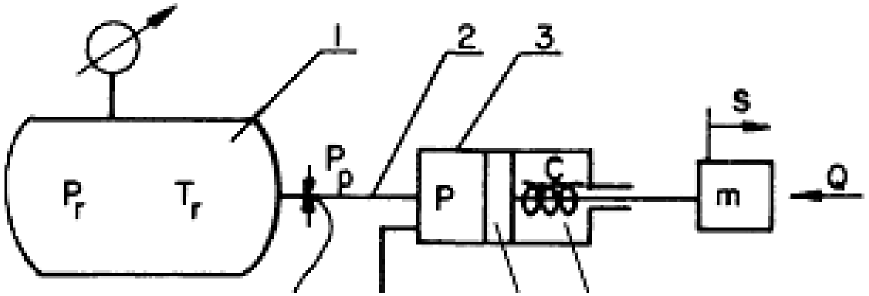
s = the displacement of the driven mass,
p = the pressure at the input of the cylinder,
F = the area of the piston,
Q = the useful and detrimental forces,
$\psi = F^3\rho/2a^2f^2$ = the coefficient of hydraulic friction of the liquid flow in the cylinder,

where
ρ = density of the liquid,
f = the area of the inlet-pipe cross section,
a = the coefficient of the inlet hydraulic resistance.

Ref: ROBOTICS Designing the Mechanisms for Automated Machinery, Ben-Zion Sandier

Dynamics..

- Pneumodrive



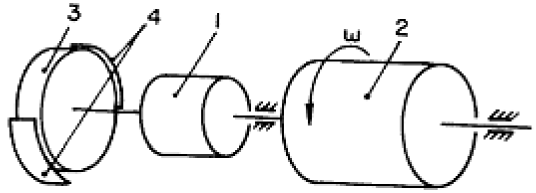
$$G = \alpha F_p p_r \sqrt{\frac{2g}{RT_r} \cdot \frac{k}{k-1} \left[\beta^{2/k} - \beta^{(k+1)/k} \right]},$$

where

G = the rate of flow,
α = coefficient of aerodynamic resistance,
F_p = cross-sectional area of pipe 2 (m^2),
p_r = air pressure in the receiver 1,
T_r = absolute temperature of the air in the receiver,
R = gas constant,
$\beta = p/p_r$ = ratio of the pressure in cylinder 3 to that in the receiver,
k = adiabatic exponent ($k = 1.41$).

Ref: ROBOTICS Designing the Mechanisms for Automated Machinery, Ben-Zion Sandier

- Brakes
  - Types of Brakes
    - Constant torque
    - Proportional-to-time torque
    - Proportional-to-displacement torque
    - Proportional-to-speed torque



1. Driving motor
2. Driven
3. Brake drum
4. Brake shoe

- The general brake equation is:

$$I\ddot{\phi} + T_b + T_r = 0$$

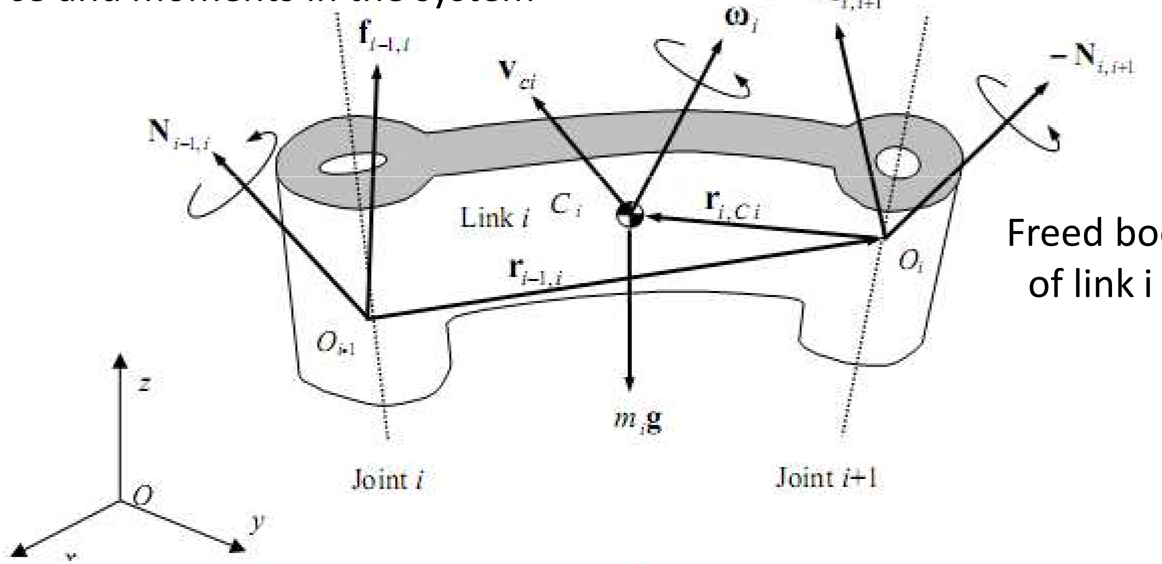
T_b= Braking torque
T_r= Resistance torque

Dynamics..

•Some Basics of Kinetics:

•Newton's equations and Eulers equations

•describes the behavior of a dynamic system in terms of force and moments in the system



Freed body diagram of link i in motion

$$\mathbf{f}_{i-1,i} - \mathbf{f}_{i,i+1} + m_i\mathbf{g} - m_i\dot{\mathbf{v}}_{ci} = 0, \qquad i = 1, \cdots, n$$

Ref: Introduction to Robotics, H. Harry Asada

Dynamics..

Some Basics of Kinetics…

- Lagrangian Formulation of Robot Dynamics
  - describes the behavior of a dynamic system in terms of work and energy stored in the system

Let q_1, ….., q_n be generalized coordinates that completely locate a dynamic system. Let T and U be the total kinetic energy and potential energy stored in the dynamic system.

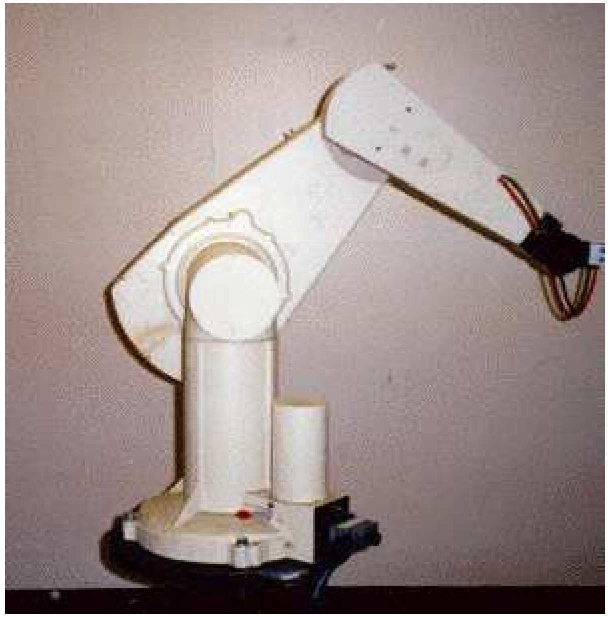
Then the Lagrangian L defined by

$$L(q_i, \dot{q}_i) = T(q_i, \dot{q}_i) - U(q_i)$$

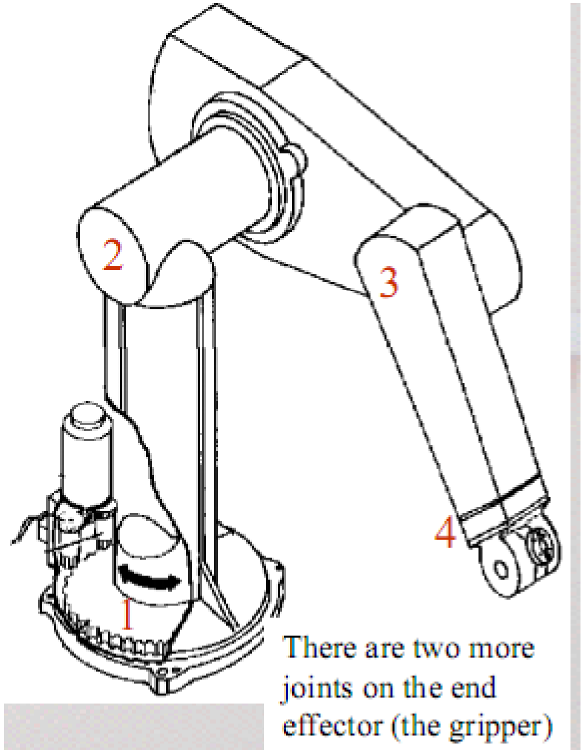
Image courtesy: RoboCup Nepal 2064

3. Introduction to Robot Kinematics

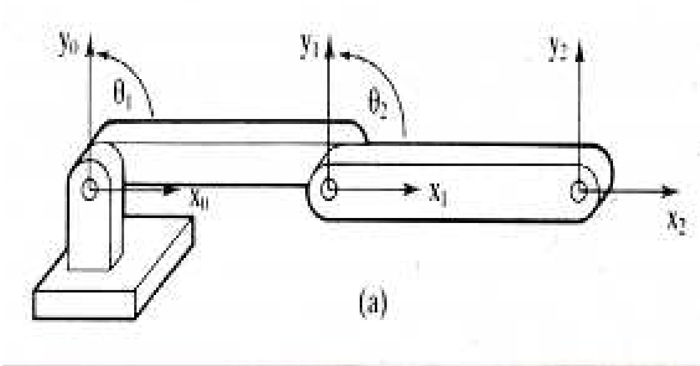
- An Example



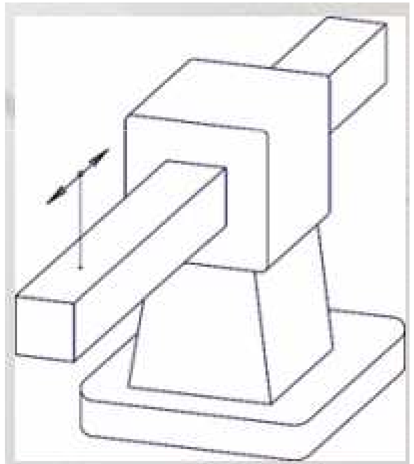
- PUMA 560 has six revolute joints



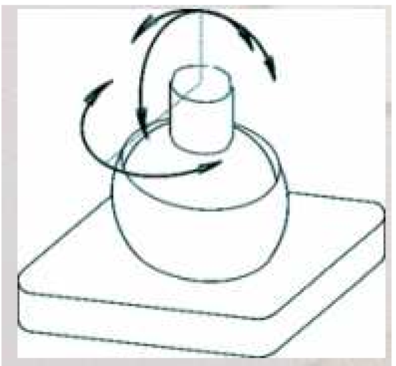
- Basics joints



Revolute joint
1 DOF (variable Y)



Prismatic joint
1 DOF (linear) (variable d)



Spherical joint
3 DOF (linear) (variables Y_1, Y_2, Y_3)

Kinematics..

- Forward Kinematics (angles to positions)

  What you are given: The length of each link
  The angle of each joint

  What you can find: The position of any point
  (i.e. it's (x, y, z) coordinates

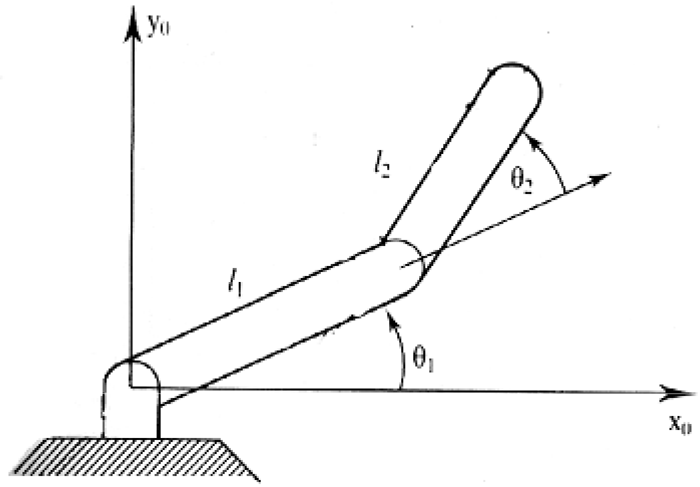
- Inverse Kinematics (positions to angles)

  What you are given: The length of each link
  The position of some point on the robot

  What you can find: The angles of each joint needed to obtain that position

Kinematics..

The Situation:
You have a robotic arm that starts out aligned with the xo-axis. You tell the first link to move by Y1 and the second link to move by Y2.



The Quest:
What is the position of the end of the robotic arm?

Solution:

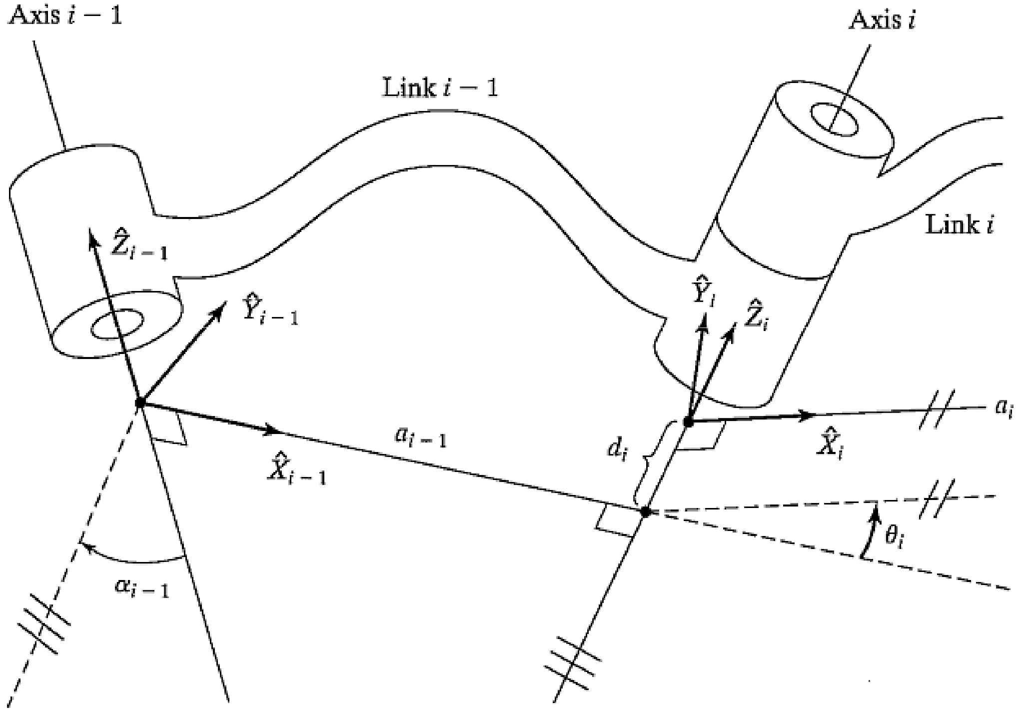
1. Geometric Approach

This might be the easiest solution for the simple situation. However, notice that the angles are measured relative to the direction of the previous link. (The first link is the exception. The angle is measured relative to it's initial position.) For robots with more links and whose arm extends into 3 dimensions the geometry gets much more tedious.

2. Algebraic Approach

Involves coordinate transformations.

- **Denavit-Hartenberg Notation**

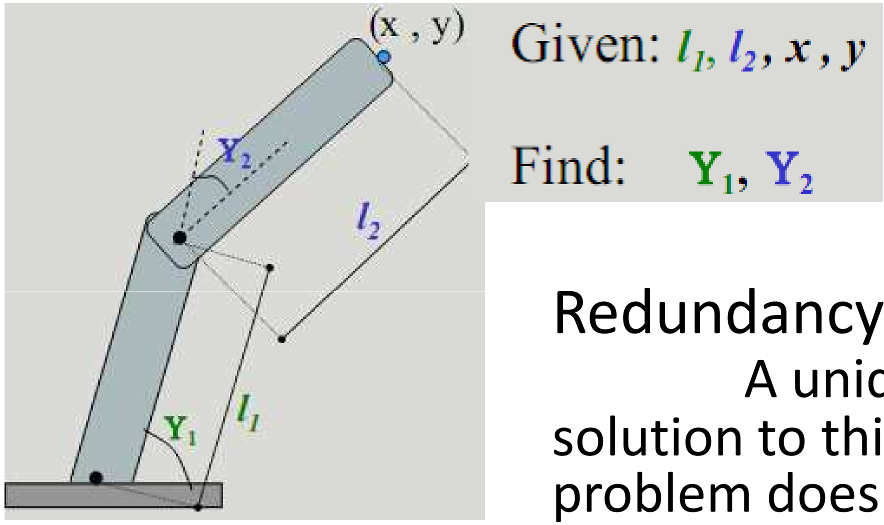


Using the Denavit-Hartenberg notation, you need 4 parameters to describe how a frame (*i*) relates to a previous frame (*i -1*).

THE PARAMETERS/VARIABLES: α, ***a* , *d*,** Y

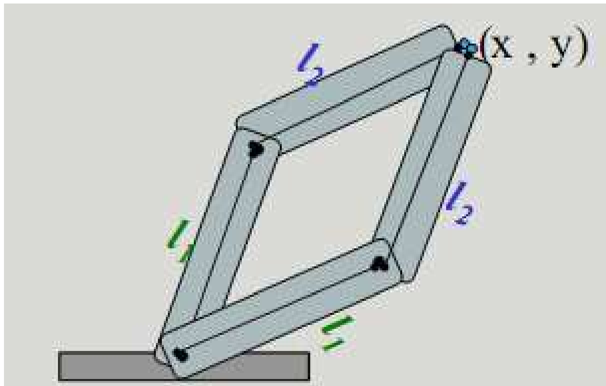
Kinematics..

- Inverse Kinematics of a Two Link Manipulator



Redundancy:

A unique solution to this problem does not exist. Notice, that using the "givens" two solutions are possible. Sometimes no solution is possible.

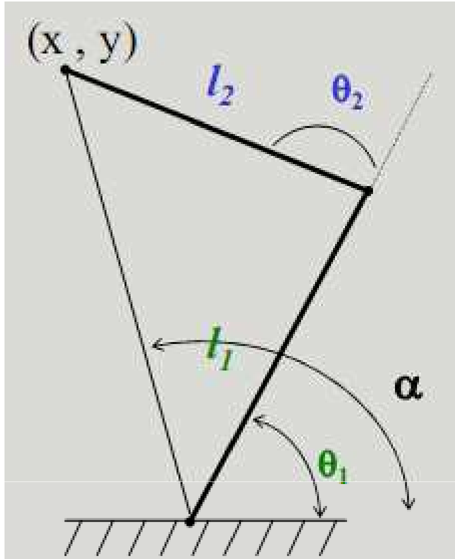


Kinematics..

- Geometric solution

$$\theta_1 = \arctan 2\left(\frac{y}{x}\right) - \arcsin\left(\frac{l_2 \sin(\theta_2)}{\sqrt{x^2 + y^2}}\right)$$

$$\theta_2 = \arccos\left(\frac{x^2 + y^2 - l_1^2 - l_2^2}{2 l_1 l_2}\right)$$



- Algebric solution

$$x = l_1 c_1 + l_2 c_{1+2}$$
$$= l_1 c_1 + l_2 c_1 c_2 - l_2 s_1 s_2$$
$$= c_1(l_1 + l_2 c_2) - s_1(l_2 s_2)$$

$$y = l_1 s_1 + l_2 \sin_{1+2}$$
$$= l_1 s_1 + l_2 s_1 c_2 + l_2 s_2 c_1$$
$$= c_1(l_2 s_2) + s_1(l_1 + l_2 c_2)$$

$$c_1 = \frac{x + s_1(l_2 s_2)}{(l_1 + l_2 c_2)}$$

$$y = \frac{x + s_1(l_2 s_2)}{(l_1 + l_2 c_2)}(l_2 s_2) + s_1(l_1 + l_2 c_2)$$
$$= \frac{1}{(l_1 + l_2 c_2)}\left(x\, l_2 s_2 + s_1(l_1^2 + l_2^2 + 2 l_1 l_2 c_2)\right)$$

$$s_1 = \frac{y(l_1 + l_2 c_2) - x\, l_2 s_2}{x^2 + y^2}$$

$$\theta_1 = \arcsin\left(\frac{y(l_1 + l_2 c_2) - x\, l_2 s_2}{x^2 + y^2}\right)$$

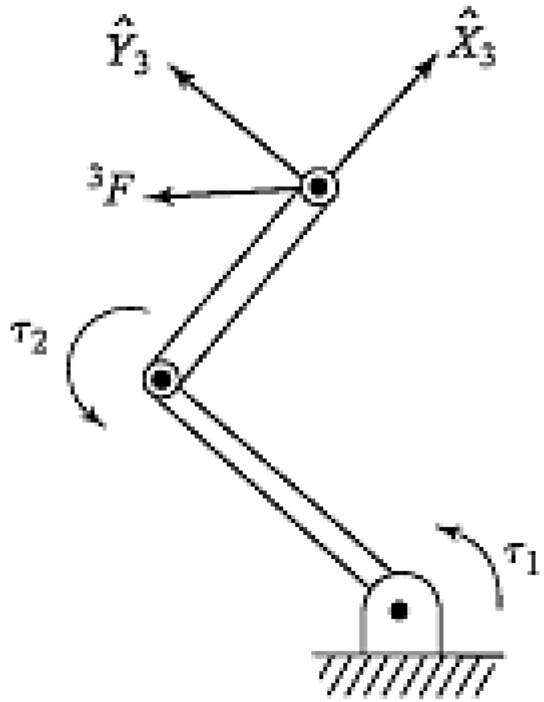
$$\theta_2 = \arccos\left(\frac{x^2 + y^2 - l_1^2 - l_2^2}{2 l_1 l_2}\right)$$

One day workshop on Robotics and Automation, 2011, Robotics Club, Pulchowk Campus

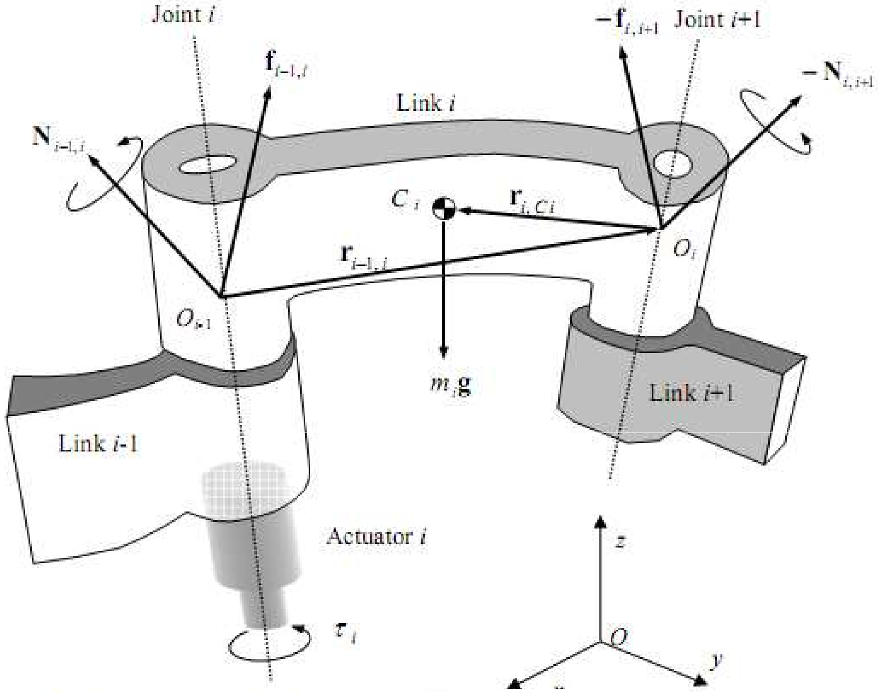
Image courtesy: RoboCup Nepal 2064

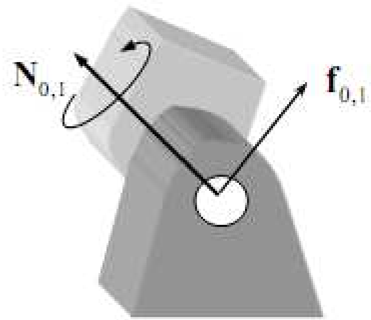
4. Introduction to Robot Statics

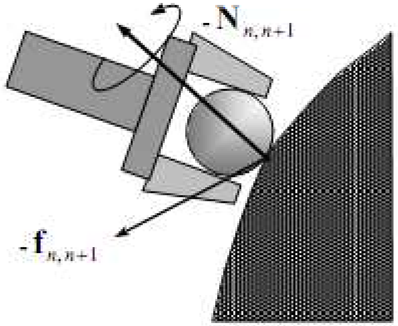
- Robots physically interact with the environment through mechanical contacts. Mating work pieces in a robotic assembly line, manipulating an object with a multi-fingered hand, and negotiating a rough terrain through leg locomotion are just a few examples of mechanical interactions.
- A robot generates a force and a moment at its end-effecter by controlling individual actuators.
- To generate a desired force and moment, the torques of the multiple actuators must be coordinated.



Statics…







$$\mathbf{f}_{i-1,i} - \mathbf{f}_{i,i+1} + m_i\mathbf{g} = \mathbf{0}, \quad i = 1,\cdots,n$$

$$\mathbf{N}_{i-1,i} - \mathbf{N}_{i,i+1} - (\mathbf{r}_{i-1,i} + \mathbf{r}_{i,Ci}) \times \mathbf{f}_{i-1,i} + (-\mathbf{r}_{i,Ci}) \times (-\mathbf{f}_{i,i+1}) = \mathbf{0}, \quad i = 1,\cdots,n$$

$$\mathbf{F} = \begin{pmatrix} \mathbf{f}_{n,n+1} \\ \mathbf{N}_{n,n+1} \end{pmatrix}$$

We call the vector F the endpoint force and moment vector, or the endpoint force for

Ref: Introduction to Robotics, H. Harry Asada

Image courtesy: RoboCup Nepal 2067

5. Manipulator Mechanism Design

- manipulator control depends not only on the rigid-body dynamics, but also upon the friction and flexibility of the drive systems
- For certain applications, the overall manipulator size, weight, power consumption, and cost will be significant factors

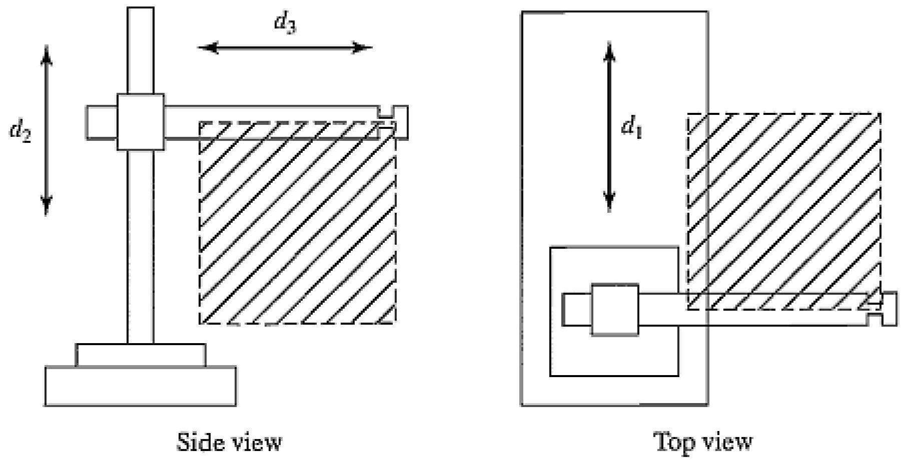
- BASING THE DESIGN ON TASK REQUIREMENTS
  - Number of degrees of freedom
    - The number of degrees of freedom in a manipulator should match the number required by the task. Not all tasks require a full six degrees of freedom.
  - Workspace
    - In performing tasks, a manipulator has to reach a number of workpieces or fixtures.
    - Depending on the kinematic design, operating a manipulator in a given application could require more or less space around the fixtures in order to avoid coffision

Manipulator Mechanism Design…

BASING THE DESIGN ON TASK REQUIREMENTS…

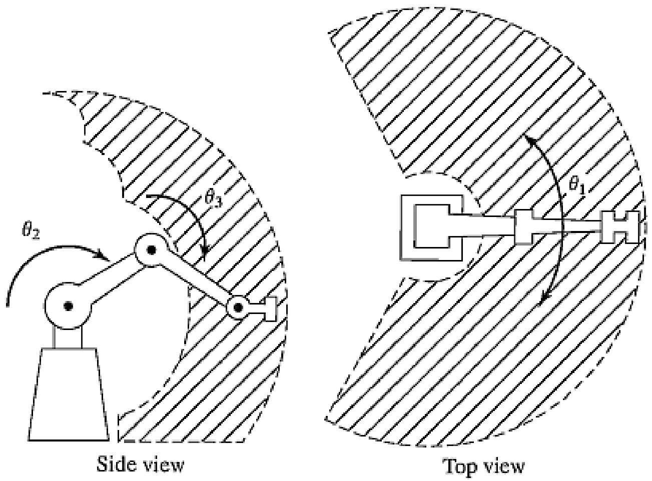
- Load capacity
  - The load capacity of a manipulator depends upon the sizing of its structural members, power-transmission system, and actuators.
- Speed
  - An obvious goal in design has been for faster and faster manipulators
  - However some process itself limits the speed rather than the manipulator. This is the case with many welding and spray-painting applications.
  - An important distinction is that between the maximum end-effector speed and the overall cycle time for a particular task.
- Repeatability and accuracy
  - High repeatability and accuracy, although desirable in any manipulator design, are expensive to achieve
  - High accuracy is achieved by having good knowledge of the link (and other) parameters.

- KINEMATIC CONFIGURATION
  - Cartesian
    - perhaps the most straightforward configuration.
    - This configuration produces robots with very stiff
    - primary disadvantage is that all of the feeders and fixtures associated with an application must lie "inside" the robot. structur



KINEMATIC CONFIGURATION…

– Articulated
  - sometimes also called ajointed, elbow, or anthropomorphic manipulator.
  - minimize the intrusion of the manipulator structure into
  - the workspace, making them capable of reaching into confined spaces.
  - They require much less overall structure than Cartesian robots, making them less expensive for applications needing smaller workspaces

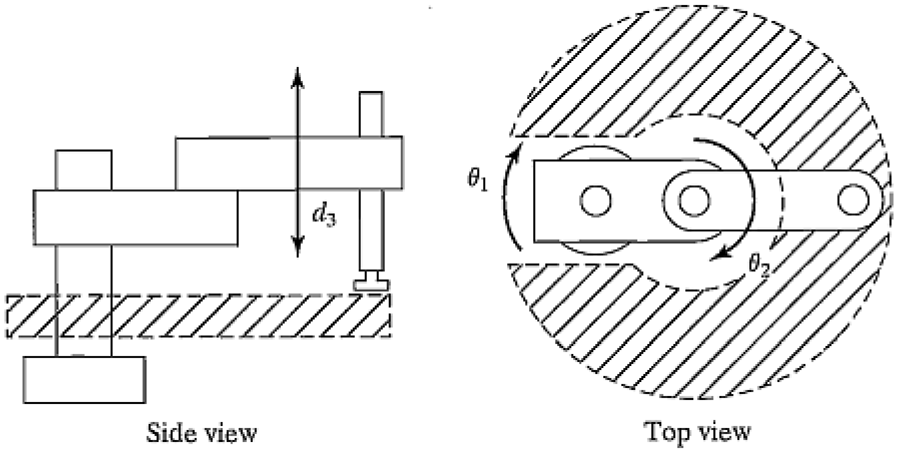


An Articulated Manipulator

KINEMATIC CONFIGURATION…

– SCARA

- Stands for "selectively compliant assembly robot arm."
- Advantage is that the first three joints don't have to support any of the weight of the manipulator or the load.
- The actuators can be made very large, so the robot can move very fast



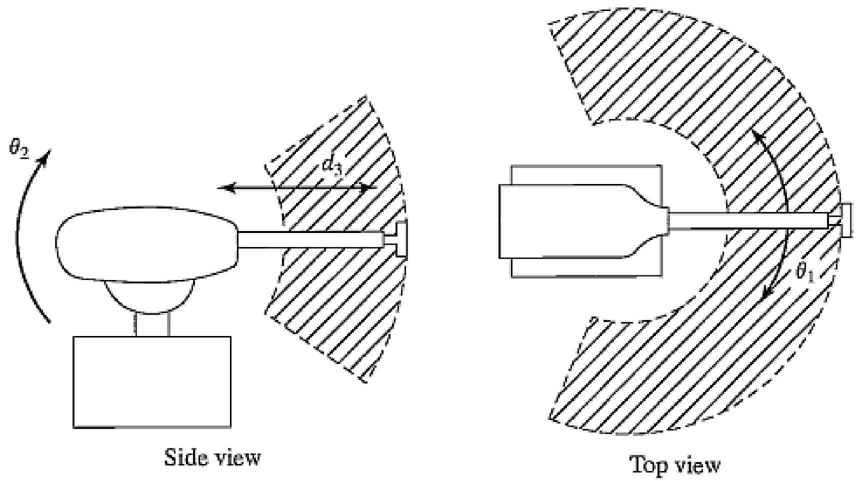
A SCARA manipulator

Manipulator Mechanism Design…

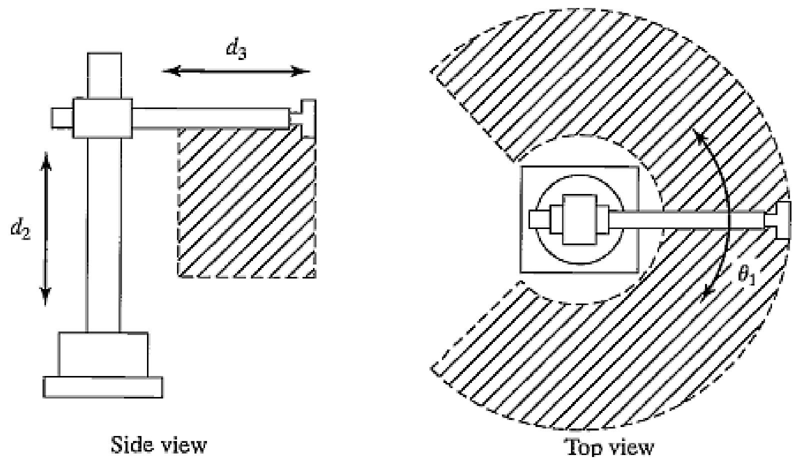
KINEMATIC CONFIGURATION…

- Spherical
  - The link that moves prismatically might telescope—or even "stick out the back" when retracted.

- Cylindrical
  - consist of a prismatic joint for translating the arm vertically, a revolute joint with a vertical axis, another prismatic joint orthogonal to the revolute joint axis, and, finally, a wrist of some sort.



A Spherical manipulator

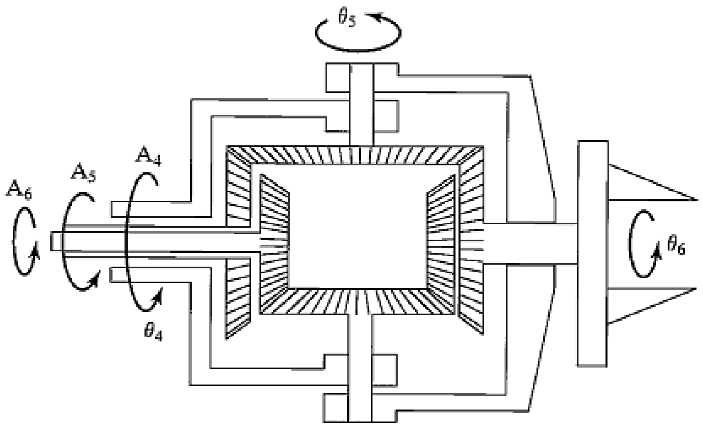


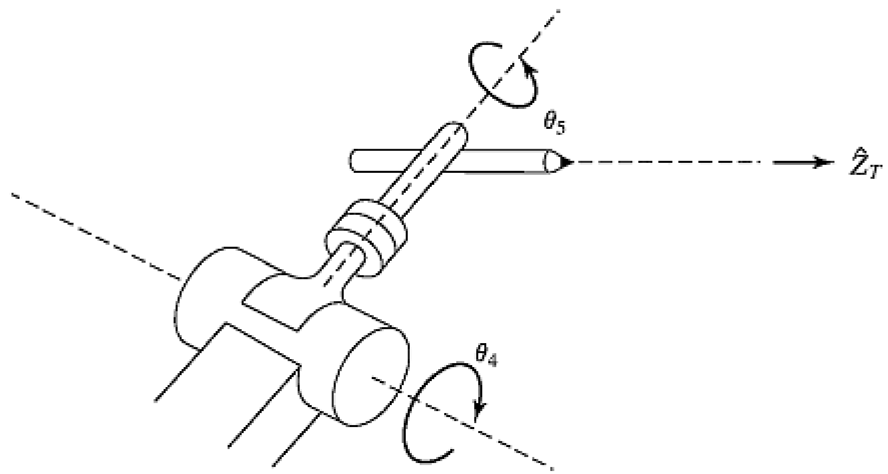
A Cylindrical manipulator

KINEMATIC CONFIGURATION…

– Wrists

- The most common wrist configurations consist of either two or three revolute joints with orthogonal, intersecting axes.





Typical wrist design of a 5-DOF welding robot.

- QUANTITATIVE MEASURES OF WORKSPACE A1TRIBUTES
- REDUNDANT AND CLOSED-CHAIN STRUCTURES
- ACTUATION SCHEMES
- STIFFNESS AND DEFLECTIONS
  - Shafts, belts, gears, links, pneumatic cylinders, brushless motors.
- POSITION SENSING
  - Resolvers, potentiometers, tachometers.
- FORCE SENSING
  - Strain gauges.

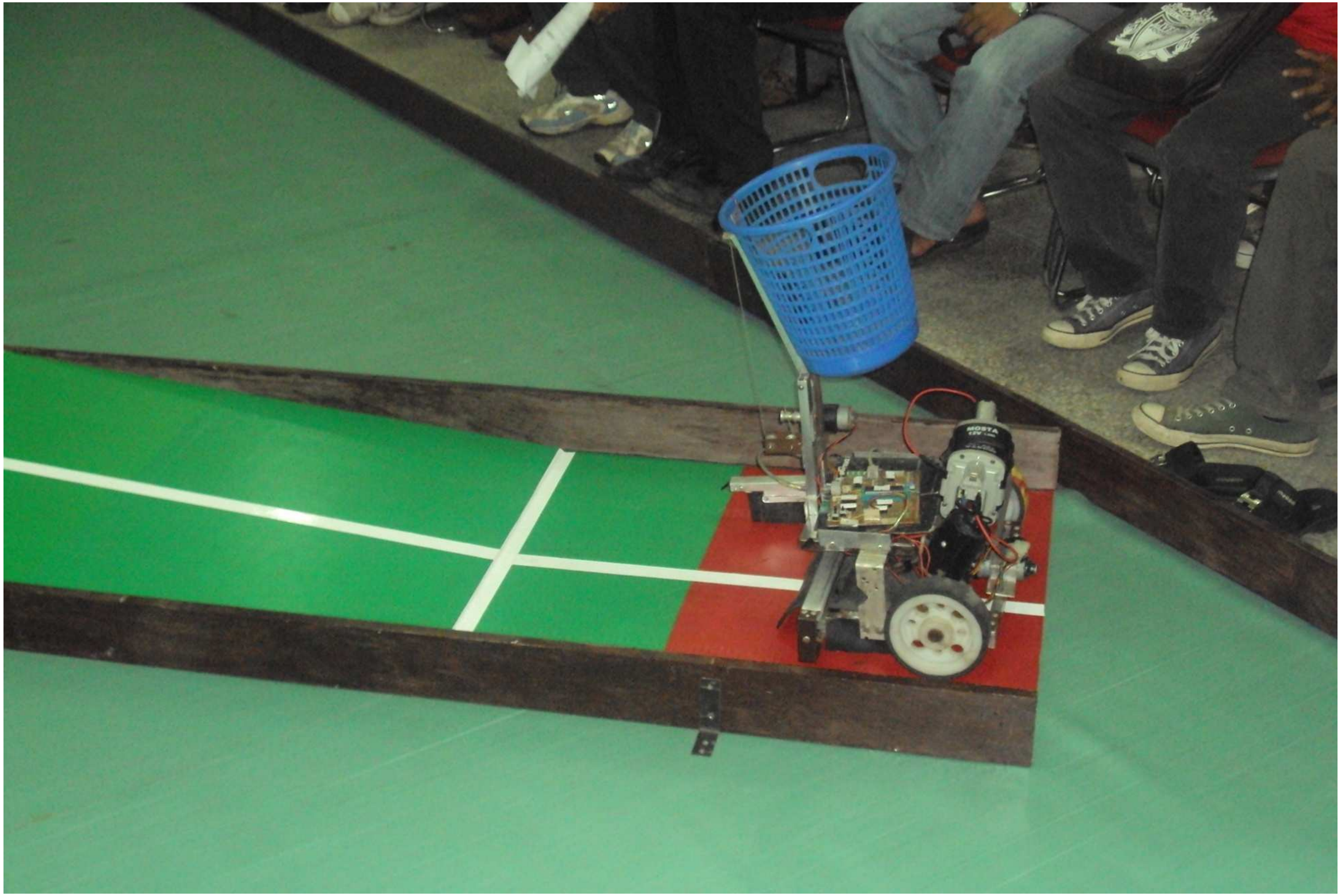
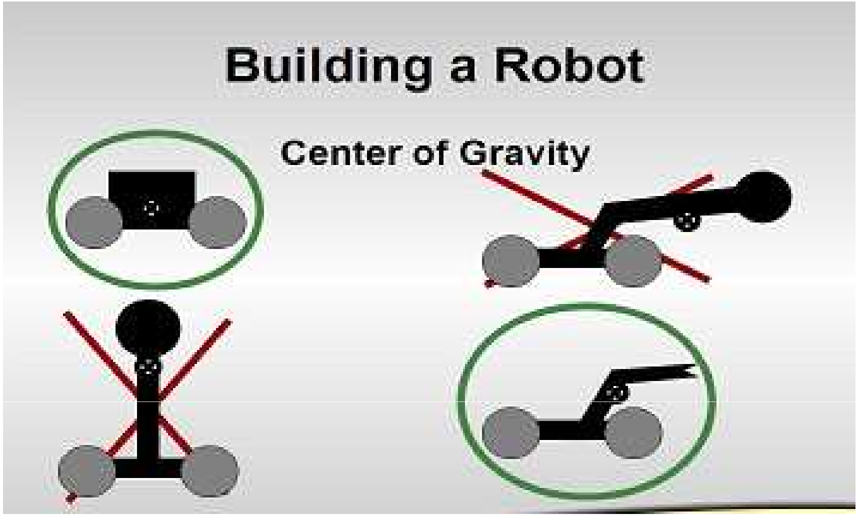


Image courtesy: RoboCup Nepal 2064

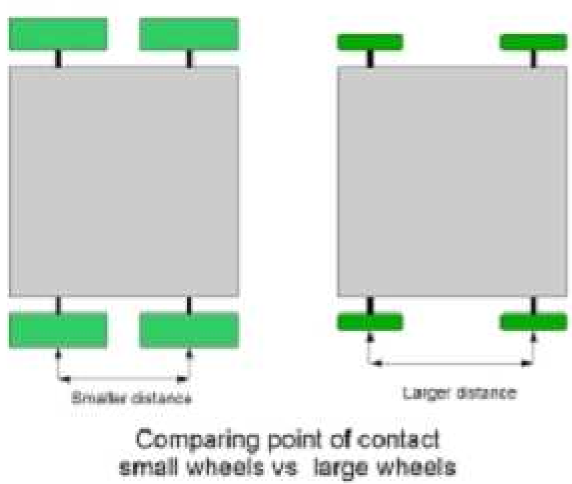
6. Building a Robot

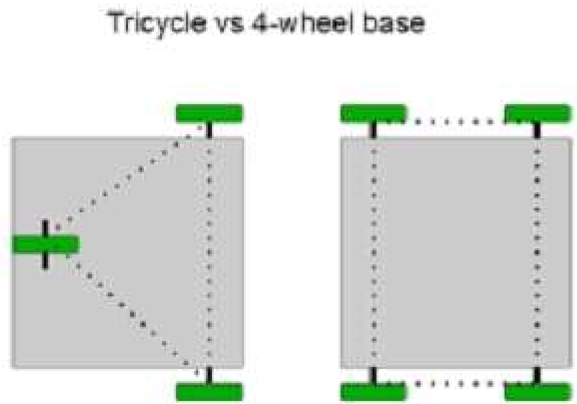
- Center of Gravity

Determining the center of gravity of your robot ?

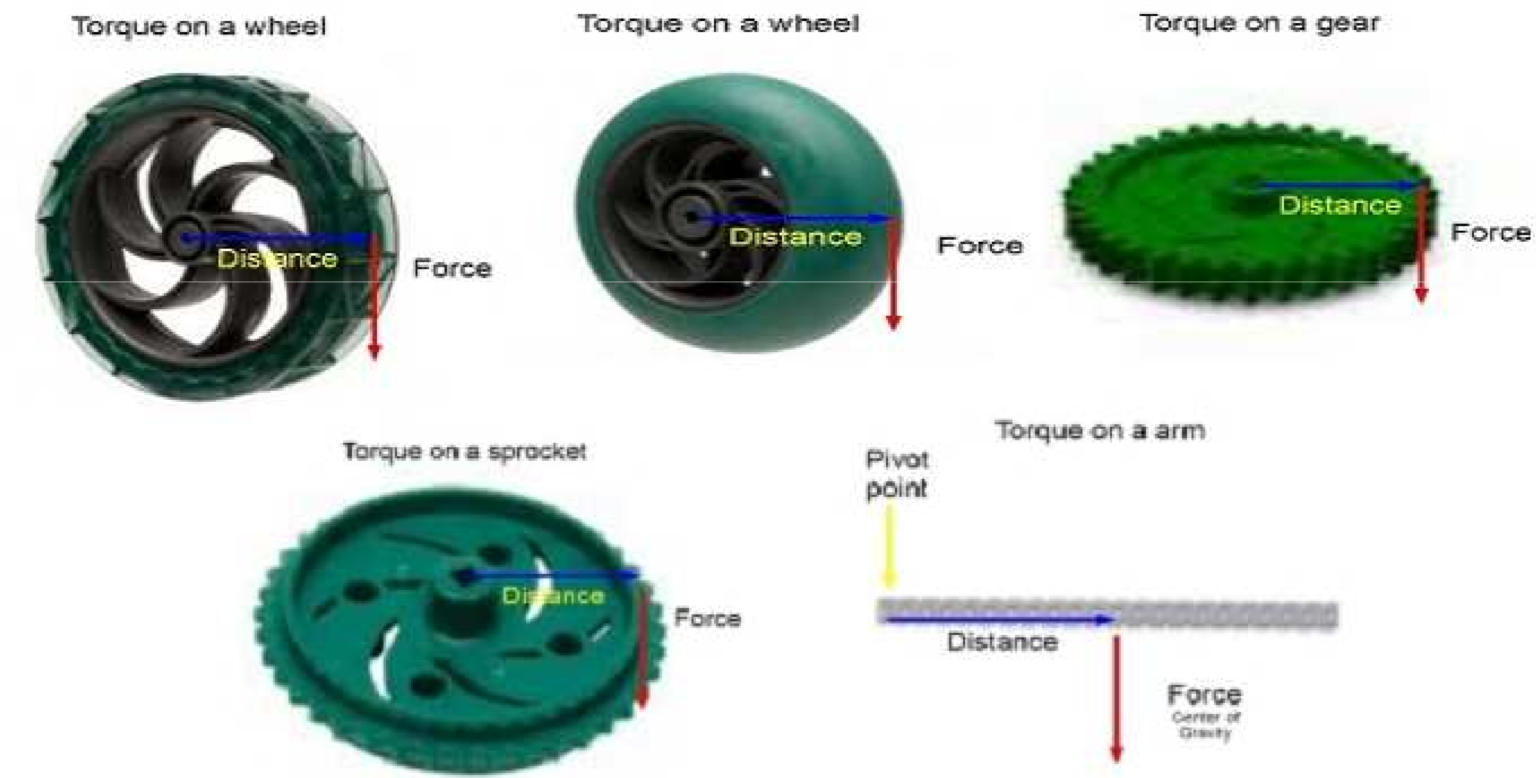


- Stability and Traction

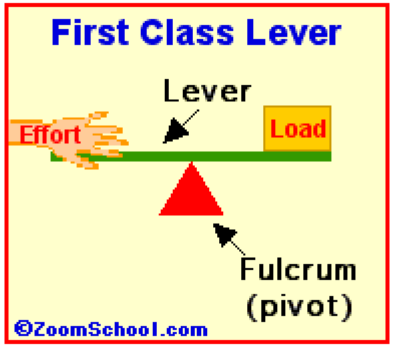


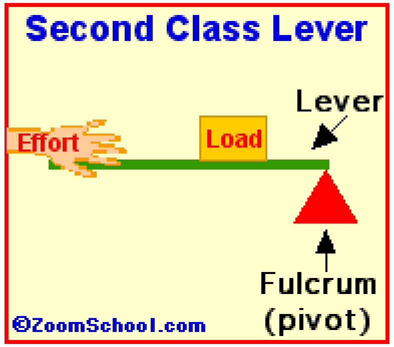


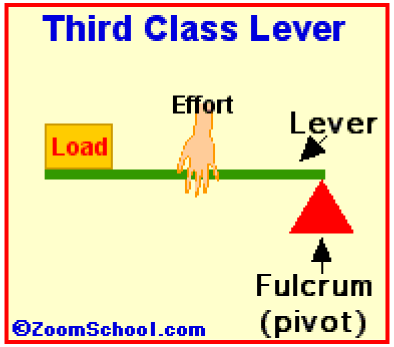
- Torque

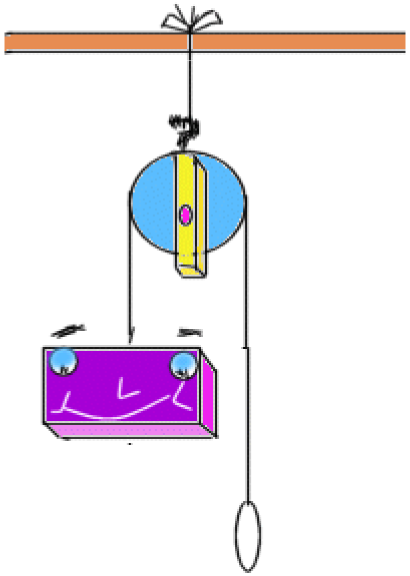

Torque on a wheel
Distance
Force
Torque on a wheel
Distance
Force
Torque on a gear
Distance
Force
Torque on a sprocket
Distance
Force
Torque on a arm
Pivot point
Distance
Force

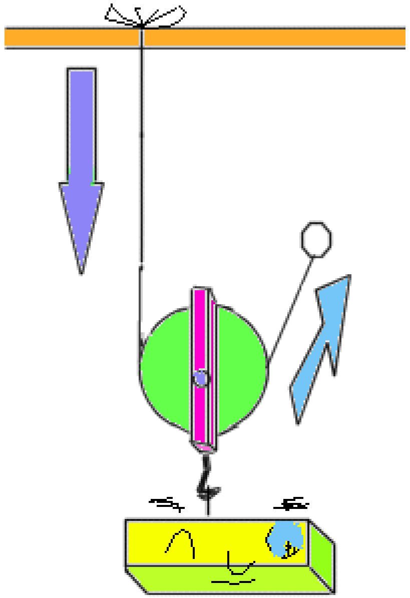
- Mechanical Advantage

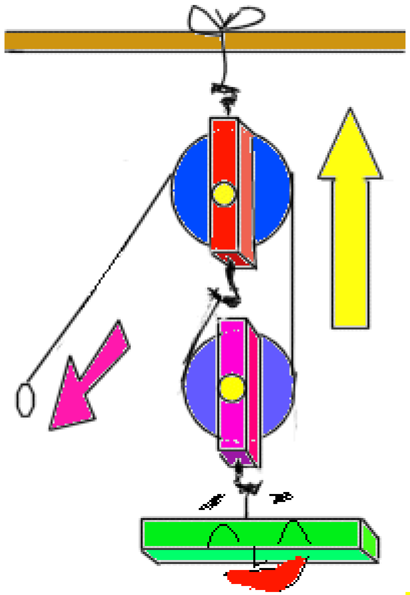












Christa McAuliffe Sabbatical Project

- Safety
  - Pinch Points
  - Sharp edges
  - Eye protection
  - Autonomous operation
  - Battery safety
  - Electrical wire

SAFETY is EVERYONE'S responsibility!
PLEASE watch out for each other!

Christa McAuliffe Sabbatical Project

Thank you

Image courtesy: RoboCup Nepal 2064