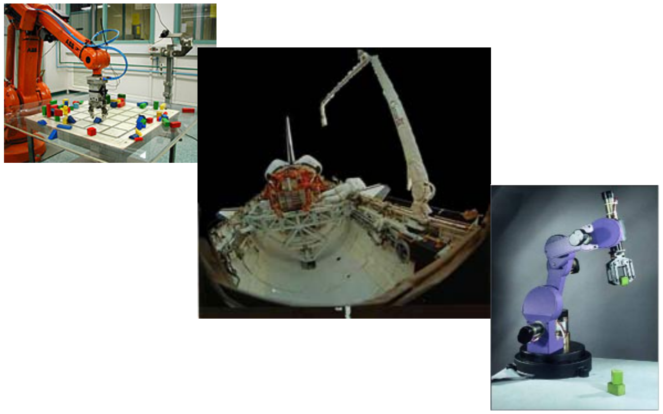
Autonomous systems

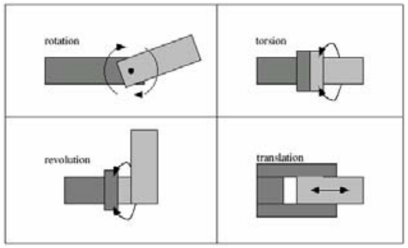
Manipulation and locomotion

Robot arms

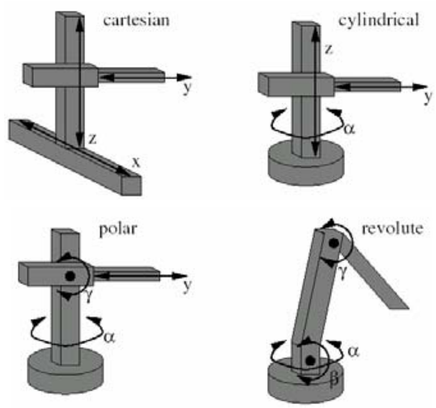


Robot arms

- Constructed out of **shoulder**, **elbow** and **wrist**.
- Each joint constitutes a degree of freedom (DOF).
- Four types of joints exist



Types of robot arms



Robot hands

- Many different types.
- Independent of arm type, just attached to end of manipulator.
- Grippers are the most basic type of hand, having two fingers.
  - Parallel gripper

  - Pinch gripper

Robot hands

- Dexterous hands (3 fingers and up).

Forward kinematics

- Kinematics: science of moving objects.

- **Forward** kinematics
  - Starting with a description of the system, compute the state in which the system shall be for a given set of parameters.
  - E.g. given a description of a robot arm and the angles of every joint, compute the exact position of the end of the arm.
  - This is easy!

Inverse kinematics

- **Inverse** kinematics
  - Starting with a description of the system, given a state you want the system to be in, how should all parameters of the system be set.

  - **This is a hard problem!**

    - The solution to an inverse kinematics problem is almost always overdetermined.

    - Some transitions are not allowed.

    - Solution should be “parsimonious”, keep your transition from one state to the other as simple as possible. This boils down to spending the least amount of energy.

Constructing a wheeled robot

- In order to construct a wheeled robot some design decisions have to be made.
- Let us focus here on the selection of motors, more specifically, on the required power of the motors.
- For this a simple model of the robot is needed…

Degrees of freedom

- Two degrees of freedom
  - **Controllable** degrees of freedom
  - **Total** degrees of freedom
- Nonholonomic robot
  - Robot with less controllable DOFs than total DOFs.
    - E.g. differential drive, ackerman drive
  - The larger the difference, the harder to control.
- Holonomic robot
  - Total DOFs = controllable DOFs.

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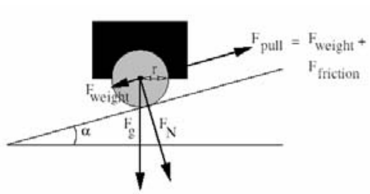
The simple vehicle model



$$F_{pull} = F_{weight} + F_{friction}$$
$$= m.g.\sin\alpha + \mu.m.g.\cos\alpha$$
$$= (\sin\alpha + \mu.\cos\alpha).m.g$$

Rule-of-thumb value for motor selection

$$\alpha = 30^\circ \text{ and } \mu = 0.5$$
$$F_{pull} \approx m.g$$

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Speed, acceleration, …

- Deserid maximum speed of the robot

$$v_{\max} = 2\pi.r.N$$

With r the radius of the wheels and N the rotational speed of the wheels.

- Power needed to drive a robot at a certain speed

$$P = F.v$$

$F = F_{pull}$ and $v = v_{max}$

- Maximum possible acceleration

$$F = m.a$$

  - But beware of slippage.

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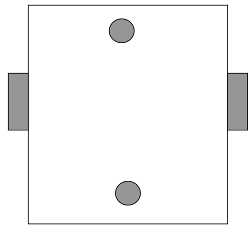
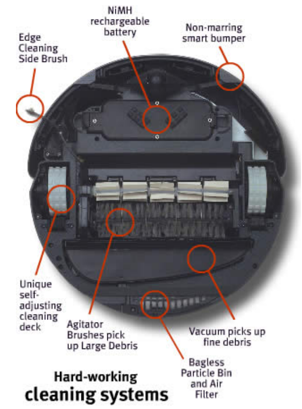
Differential drive

- Two powered wheels, left and right.
- Castor wheels.
  - Swivel wheels.
  - Ball-units.
- Advantages
  - Simple design.
  - Turn on the spot.
- Disadvantage
  - Straight-through driving often bad.



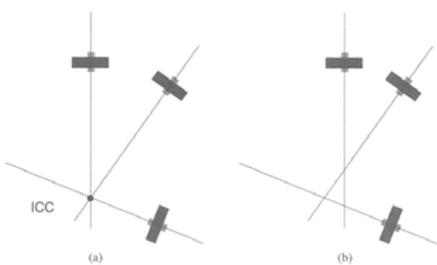
Example of differential drive

- Roomba cleaning robot



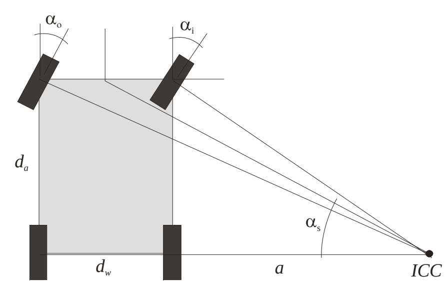
Instantaneous centre of curvature (ICC)

- In order for all wheels of a vehicle to **roll** without slipping, the axes of all wheels need to intersect in one point.
- This point is called the ICC.



Ackerman drive

- Four wheels, just as a car.
- Front wheels for steering.
- When turning, all wheels turn as different speeds.
  - Is resolved for the back wheels by a differential gear.



Ackerman equations

- Front wheels need different steering angle, to avoid slippage. Given by…

$$a = \frac{d_a}{\tan \alpha_i} - d_w$$

$$\alpha_i = \tan^{-1}\left(\frac{d_a}{a}\right)$$

$$\tan \alpha_s = \frac{d_a}{a + \frac{d_w}{2}}$$

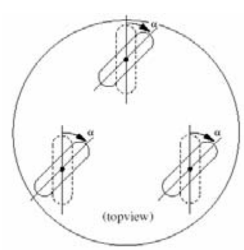
Why Ackerman?

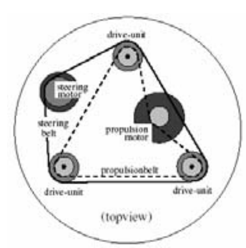
- Ackerman driven vehicles can carry heavy payloads.
- All roads and infrastructure are designed for Ackerman driven vehicles.

- Not a good choice for small robots!
  - The inverse kinematics are extremely complex.

Synchro drive

- All wheels are at same angle and are powered.
- Two motors are used.



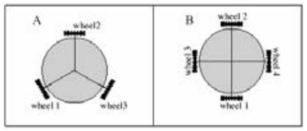


Synchro drive examples

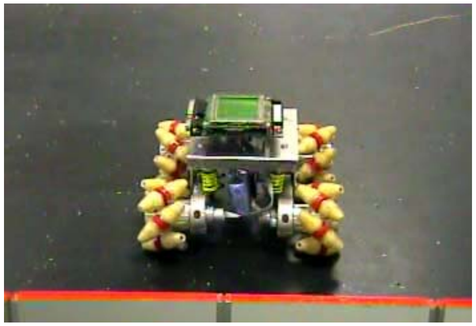
- Trashcan robot
  - iRobot's B21, has a four wheel synchro drive

Omni-directional drive

- Wheel with free-rotating tubes.
- Several possible configurations
  - Three motors, and three wheels.
  - Two motors, and four wheels.

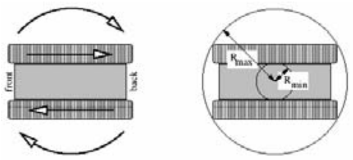


Omni-drive, example



Tracked drive

- Same principle as differential drive, but instead of wheels the robot has tracks.
- Good grip, low slippage. Excellent for rough terrain.
- Very unpredictable rotation.



Tracked drive

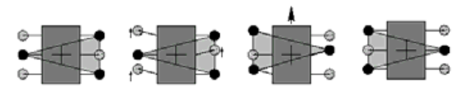
- Scout robot from Real World interfaces. Built as rescue robot to negotiate difficult terrain.

Legged locomotion

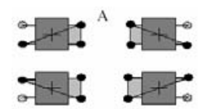
- Advantages
  - Allows negotiating of difficult terrain (rocky surface, stairs).
  - Allows climbing.
  - Allows manipulation.
  - Less contact with surface (no damage by wheels).
- Disadvantage
  - Mechanical complexity.
  - Power consumption.
- Two types of motion
  - Static walking.
  - Dynamic walking = “controlled falling”.

Static gaits

- Centre of gravity need to be within support surface of robot.
  - Six-legged walker.

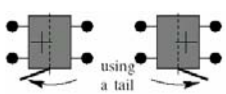


  - Four-legged walker
    - Problematic, as centre of gravity is just out of support surface.



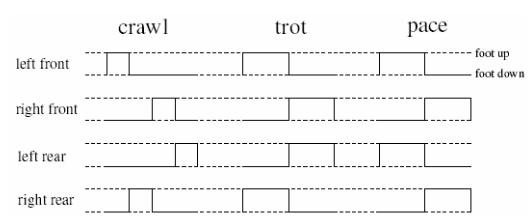
Static gait

- Solutions for the four-legged walker
  - Move feet in a particular order.
  - Shift centre of gravity by shifting a weight.
  - Shift centre of gravity by lifting robot to one side (eg. Aibo).
  - Swing a tail.



Gaits

- “Walking modes”



MIT Leglab

MIT Leglab