Autonomous Mobile Robot

Lecture Set – 02

Locomotion

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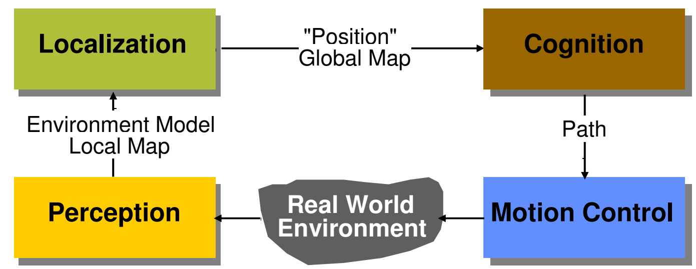
Robot Vision Lab

Locomotion Concepts

- Concepts
- Legged Locomotion
- Wheeled Locomotion



Locomotion Concepts

- Principles Found in Nature

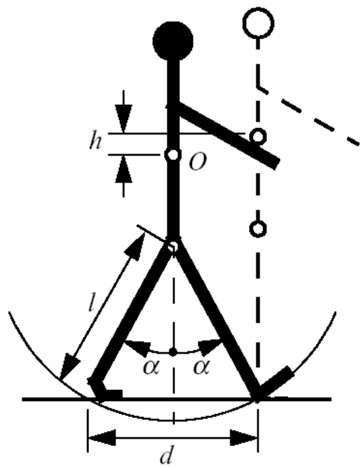
Type of motion	Resistance to motion	Basic kinematics of motion
Flow in a Channel	Hydrodynamic forces	Eddies
Crawl	Friction forces	Longitudinal vibration
Sliding	Friction forces	Transverse vibration
Running	Loss of kinetic energy	Oscillatory movement of a multi-link pendulum
Jumping	Loss of kinetic energy	Oscillatory movement of a multi-link pendulum
Walking	Gravitational forces	Rolling of a polygon (see figure 2.2)

Locomotion Concepts

- Concepts found in nature
  - Difficult to imitate technically
- Most technical systems use wheels or caterpillars
- Rolling is most efficient, but not found in nature
  - Nature never invented the wheel!
- However, the movement of a walking biped is close to rolling

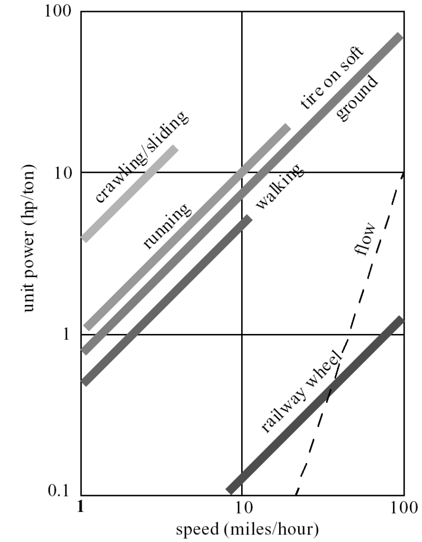
Walking of a Biped

- Biped walking mechanism
  - Not to far from real rolling
  - Rolling of a polygon with side length equal to the length of the step
  - The smaller the step gets, the more the polygon tends to a circle (wheel)
- However, fully rotating joint was not developed in nature



Walking or Rolling

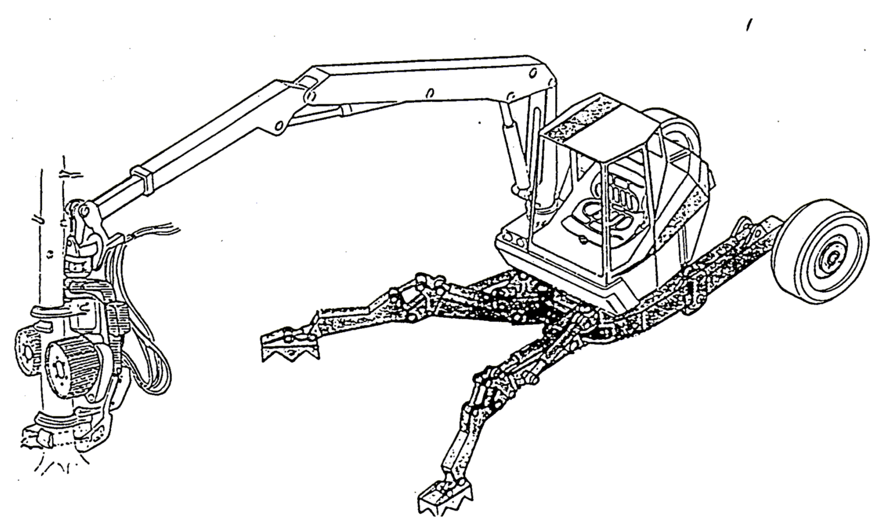
- Number of actuators
- Structural complexity
- Control expense
- Energy efficient
  - Terrain (flat ground, soft ground, climbing, etc.)
- Movement of the involved masses
  - Walking/running includes up and down movement of COG
  - Some extra losses



Announcements – 10/2/08

- Lecture slides are uploaded to school's ecourse website
- Possible projects will be given next week

RoboTrac, a hybrid wheel-leg vehicle



Characterization of Locomotion Concept

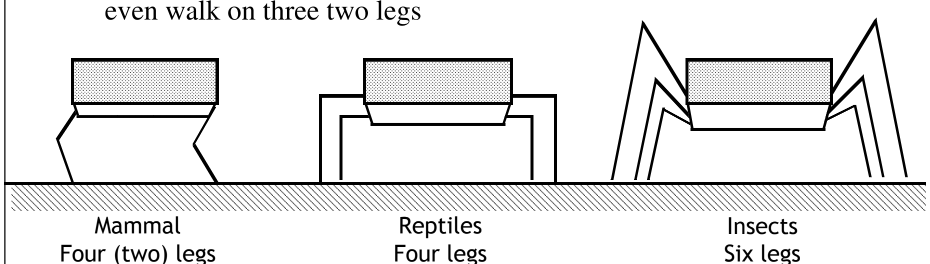
- Locomotion
  - Physical interaction between the vehicle and its environment
- Locomotion is concerned with interaction forces, and the mechanisms and actuators that generate them (same as manipulator)
- The most important issues in locomotion are:
  - Stability
  - Characteristics of contact
  - Type of environment

The Most Important Issues in Locomotion

- Stability
  - Number of contact points
  - Center of gravity
  - Static/dynamic stabilization
  - Inclination of terrain
- Characteristics of contact
  - Contact point or contact area
  - Angle of contact
  - friction
- Type of environment
  - Structure
  - Medium (water, air, soft or hard ground)

Mobile Robots with Legs (Walking Machines)

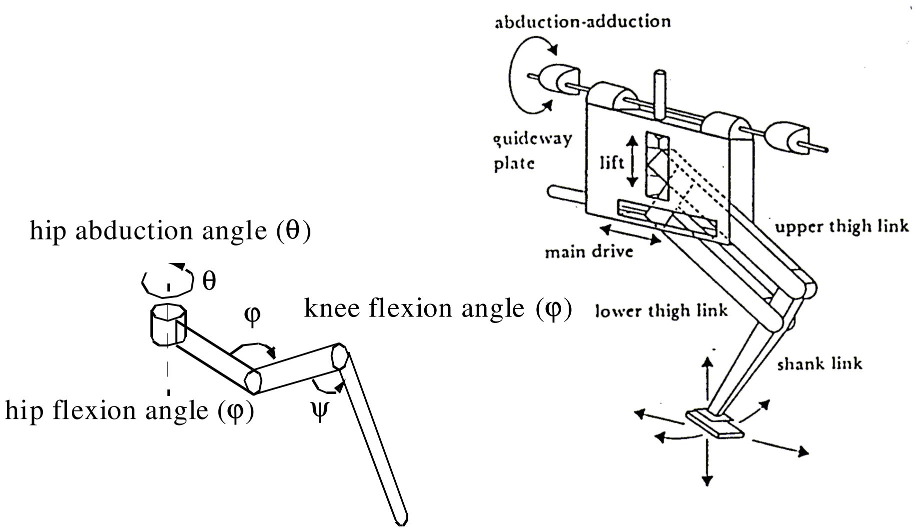
- The fewer legs the more complicated the locomotion
  - Stability, at least three legs are required for static stability
- During walking some legs are lifted
  - Thus loosing stability?
- For static walking at least 6 legs are required
  - Babies have to learn for quite a while until they are able to stand or even walk on three two legs



Number of Joints of Each Leg (DOF)

- A minimum of <u>two</u> DOF is required to move a leg forward
  - A lift and a swing motion
  - Sliding free motion in more than only one direction not possible
- <u>Three</u> DOF for each leg in most cases
- <u>Fourth</u> DOF for the ankle joint
  - Might improve walking
  - However, additional joint (DOF) increase the complexity of the design and especially the locomotion control

Examples of Legs with 3 DOF



The Number of Possible Gaits

- The gait is characterized as the sequence of lift and release events of the individual legs
  - It depends on the number of legs
  - The number of possible events N for a walking machine with k legs is:

$$N = (2k - 1)!$$

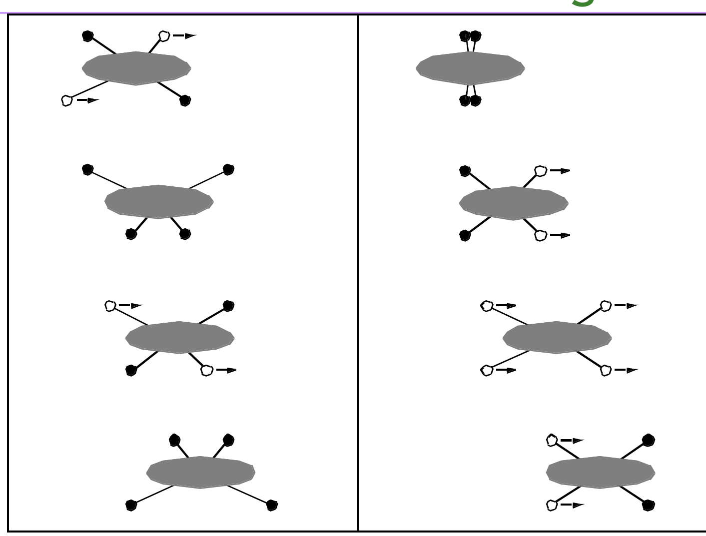
- For a biped walker ($k = 2$) the number of possible events N is:

$$N = (2k - 1)! = 3! = 6$$

  - The 6 different events are:
    lift right leg / lift left leg / release right leg / release left leg / lift both legs together / release both legs together
- For a robot with 6 legs (hexapod) N is already

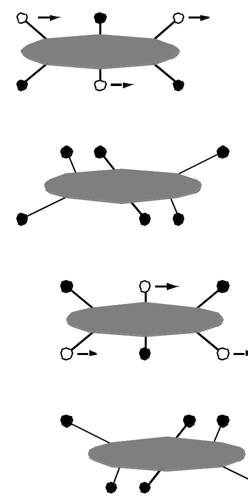
$$N = 11! = 39{,}916{,}800$$

Most Obvious Gaits with 4 Legs



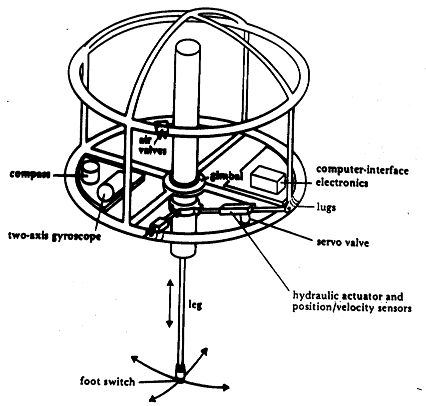
Changeover Walking Galloping

Most Obvious Gait with 6 Legs (Static)



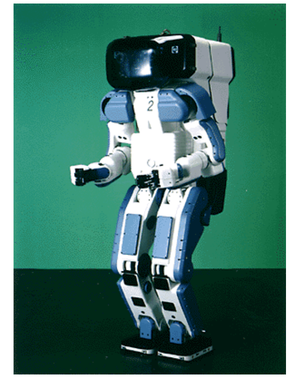
Examples of Walking Machines

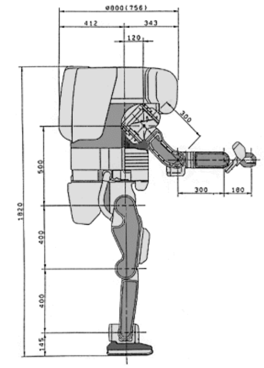
- No industrial applications up to date, but a popular research field
- The Hopping Machine



Humanoid Robots

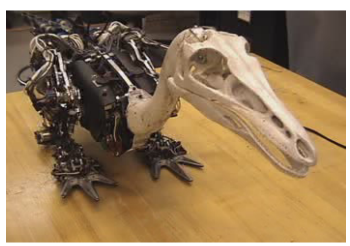
- P2 from Honda
  - Maximum Speed: 2 km/h
  - Autonomy: 15 min
  - Weight: 210 kg
  - Height: 1.82 m
  - Leg DOF: 2*6
  - Arm DOF: 2*7

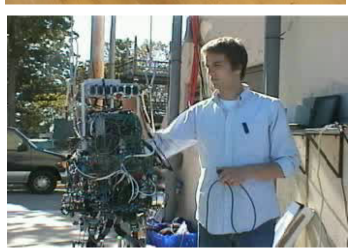




Bipedal Robots

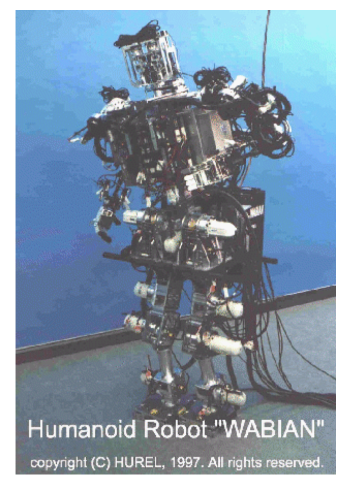
- Leg Laboratory from MIT
  - Spring Flamingo the bipedal running machine
  - “Troody” Dinosaur like robot
  - “M2” Humanoid robot
- More information: http://www.ai.mit.edu/projects/leglab/





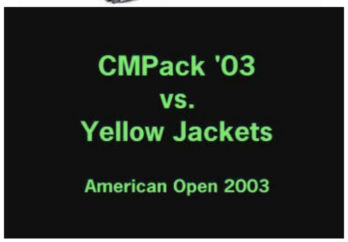
Humanoid Robots

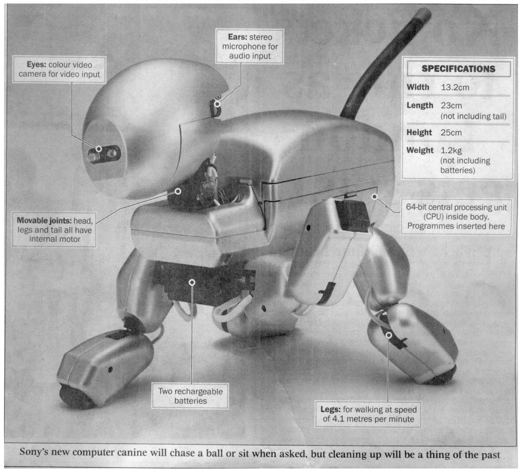
- Wabian build at Waseda University in Japan
  - Weight: 107 kg
  - Height: 1.66 m
  - DOF in total: 43



Walking Robots with 4 Legs (Quadruped)

- Artificial Dog Aibo from

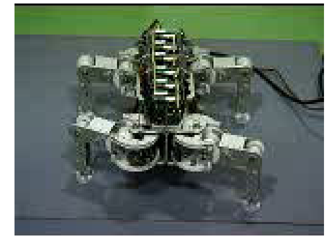




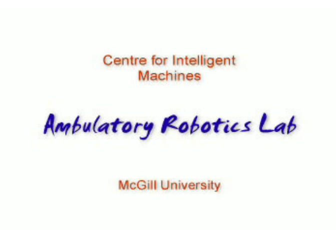
Sony's new computer canine will chase a ball or sit when asked, but cleaning up will be a thing of the past

Walking Robots with 4 Legs (Quadruped)

- Titan VIII, a quadruped robot, Tokyo Institute of Technology
  - Weight: 19 kg
  - Height: 0.25 m
  - DOF: 4*3



Walking Robots with 4 Legs (Quadruped)

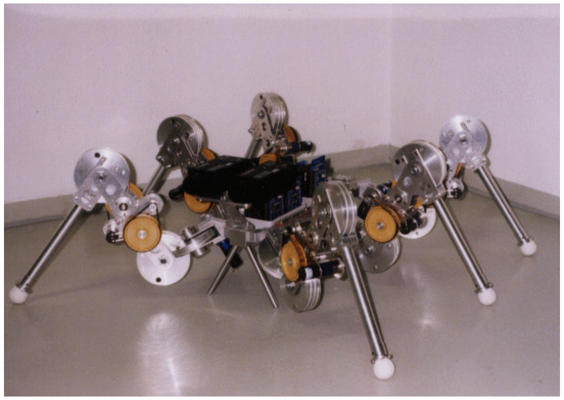


Walking Robots with 6 Legs (Hexapod)

- Most popular because static stable walking possible
- The human guided hexapod of Ohio State University
  - Maximum Speed: 2.3 m/s
  - Weight: 3.2 t
  - Height: 3 m
  - Length: 5.2 m
  - No. of legs: 6
  - DOF in total: 6*3

Walking Robots with 6 Legs (Hexapod)

- Lauron II, University of Karlsruhe
  - Maximum Speed: 0.5 m/s
  - Power Consumption: 10 W
  - Weight: 6 kg
  - Height: 0.3 m
  - Length: 0.7 m
  - No. of legs: 6
  - DOF in total: 6*3



Suggested topics for presentation

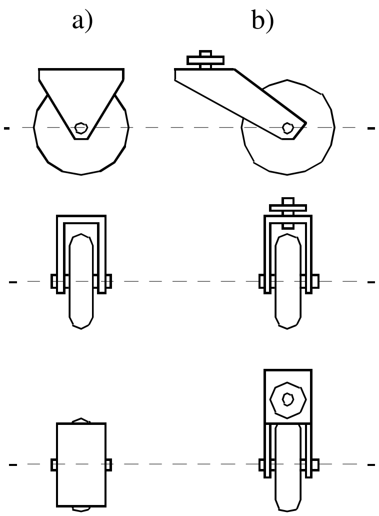
- pp. 92 – 96, 4.1.2
- pp. 97 – 101, 4.1.3 – 4.1.4
- pp. 101 – 103, 4.1.5 & pp. 115 – 117, 4.1.7
- pp. 104 – 111, 4.1.6 – 4.1.6.1
- pp. 111 – 115, 4.1.6.2
- pp. 117 – 122, 4.1.8 – 4.1.8.1
- pp. 122 – 129, 4.1.8.2 – End of “Depth from focus”
- pp. 129 – 138. stereo vision – End of 4.1.8.2
- pp. 138 – 145, 4.1.8.3 – 4.1.8.4
- pp. 145 – 150, 4.2
- pp. 151 – 159, 4.3 – 4.3.1.1
- pp. 159 – 165, 4.3.1.2 – 4.3.2
- pp. 166 – 171, 4.3.2.1 – Dynamic thresholding
- pp. 171 – 175, Straight edge extraction – End of 4.3.2.1
- pp. 175 – 180, 4.3.2.2

Mobile Robots with Wheels

- Wheels are the most appropriate solution for most applications
- Three wheels are sufficient and to guarantee stability
- With more than three wheels a flexible suspension is required
- Selection of wheels depends on the application

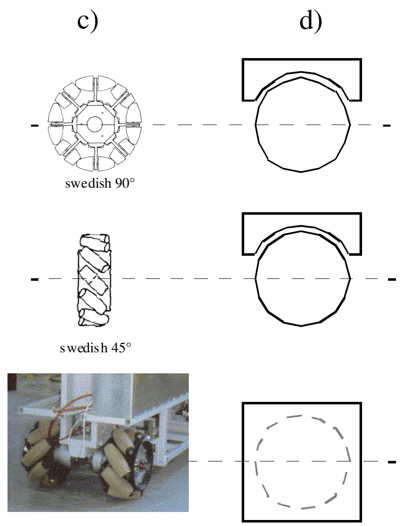
The Four Basic Wheel Types

- a) Standard wheel:
  - Two degrees of freedom; rotation around the (motorized) wheel axle and the contact point
- b) Castor wheel:
  - Two degrees of freedom; rotation around the wheel axle, the contact point and the castor axle



The Four Basic Wheel Types

- c) Swedish wheel:
  - Three degrees of freedom; rotation around the (motorized) wheel axle, around the rollers and around the contact point
- d) Ball or spherical wheel:
  - Suspension technically not solved

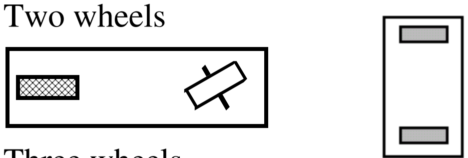


Characteristics of Wheeled Robots

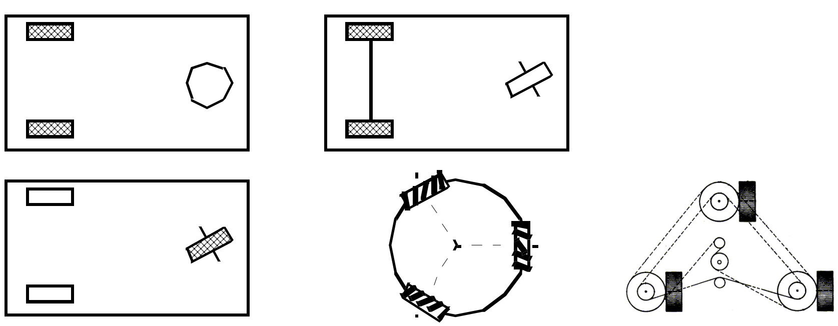
- Stability of a vehicle is guaranteed with 3 wheels
  - Center of gravity is within the triangle formed by the ground contact point of the wheels
- Stability is improved by 4 and more wheels
  - However, this arrangements are hyperstatic and require a flexible suspension system
- Bigger wheels allow to overcome higher obstacles
  - But they require higher torque or reductions in the gear box
- Most arrangements are non-holonomic (see chapter 3)
  - Require high control effort
- Combining actuation and steering on one wheel makes the design complex and adds additional errors for odometry

Different Arrangements of Wheels I

- Two wheels



- Three wheels

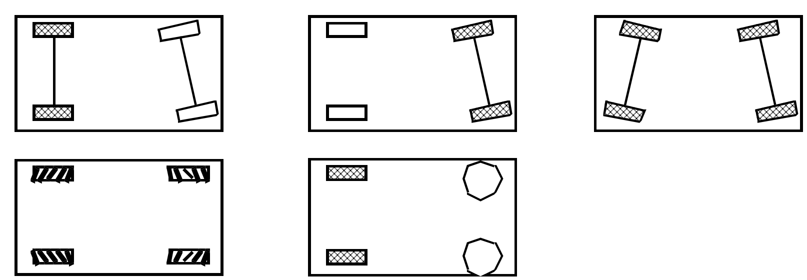


Omnidirectional Drive

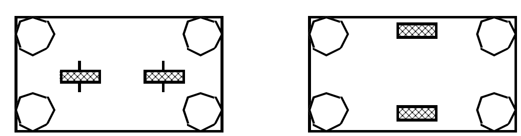
Synchro Drive

Different Arrangements of Wheels II

- Four wheels



- Six wheels

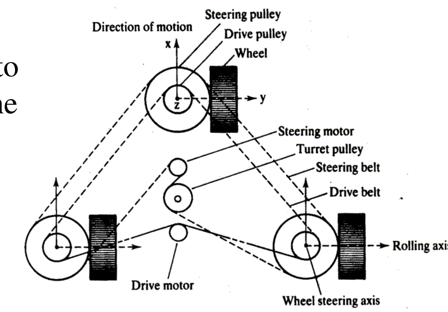


A Two Wheel Differential Drive Robot

- Cye, a commercially available domestic robot that can vacuum and make deliveries in the home, is built by Probotics, Inc.

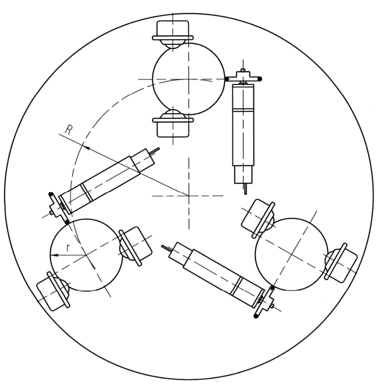
Synchro Drive

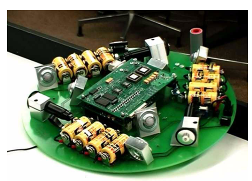
- All wheels are actuated synchronously by one motor
  - Defines the speed of the vehicle
- All wheels steered synchronously by a second motor
  - Sets the heading of the vehicle
- The orientation in space of the robot frame will always remain the same
  - It is therefore not possible to control the orientation of the robot frame

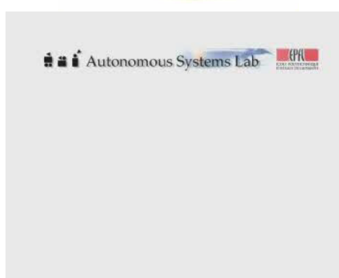


Tribolo

- Omnidirectional Drive with 3 Spherical Wheels

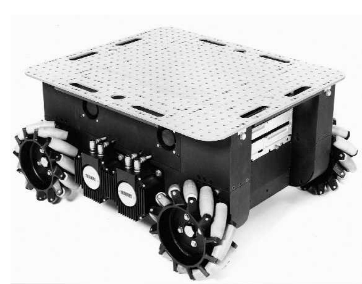


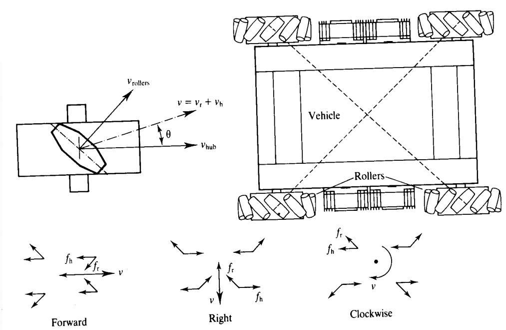




Uranus, CMU

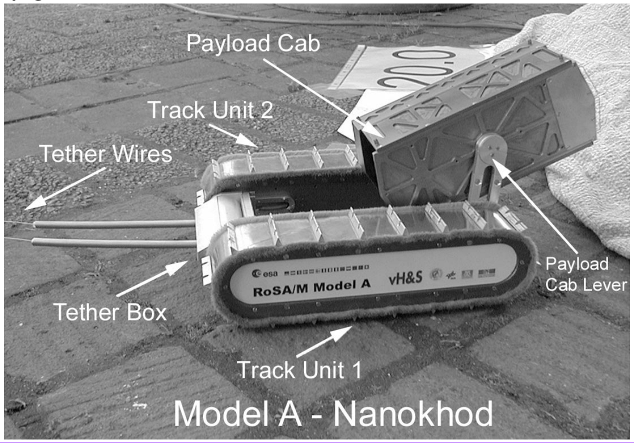
- Omnidirectional Drive with 4 Wheels
- Movement in the plane has 3 DOF
  - thus only three wheels can be independently controlled
  - It might be better to arrange three swedish wheels in a triangle





Caterpillar

- The NANOKHOD II, developed by von Hoerner & Sulger GmbH and Max Planck Institute, Mainz for European Space Agency (ESA) will probably go to Mars



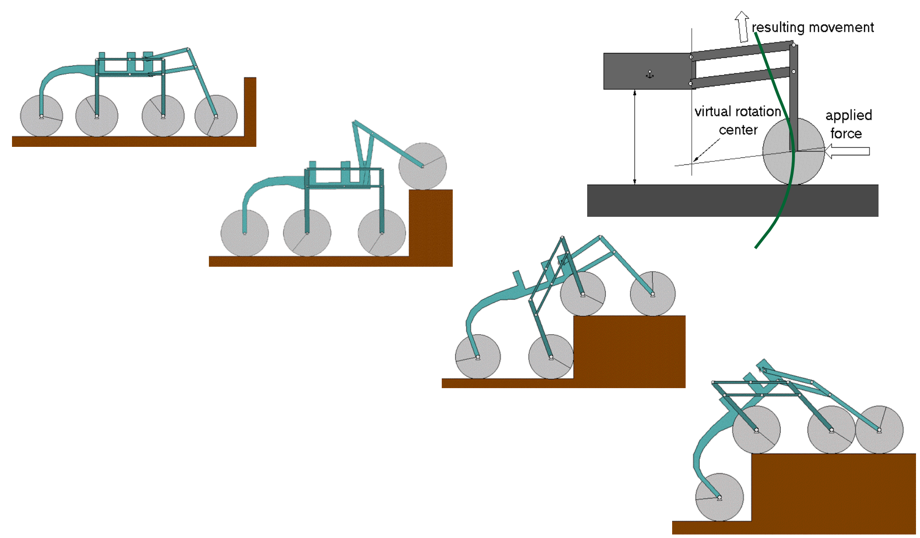
Stepping / Walking with Wheels

- SpaceCat, and micro-rover for Mars, developed by Mecanex Sa and EPFL for the European Space Agency (ESA)

SHRIMP

- A Mobile Robot with Excellent Climbing Abilities
- Objective
  - Passive locomotion concept for rough terrain
- Results: The Shrimp
  - 6 wheels
    - one fixed wheel in the rear
    - two boogies on each side
    - one front wheel with spring suspension
  - robot sizing around 60 cm in length and 20 cm in height
  - highly stable in rough terrain
  - overcomes obstacles up to 2 times its wheel diameter

SHRIMP Adapts Optimally to Rough Terrain



The Personal Rover