ME 598: Introduction to Robotics

Lecture 7: Introduction to Autonomous Mobile Robots
Mobile Robot Locomotion

Stevens Institute of Technology
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Date:
By:

Slides adapted from Dr. David J. Cappelleri and
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STEVENS INSTITUTE of TECHNOLOGY
THE INNOVATION UNIVERSITY

Introduction to Autonomous Mobile Robots

Introduction to Autonomous Mobile Robots: Autonomous Mobile Robots

- The three key questions in Mobile Robotics
  - ***Where am I ?***
  - ***Where am I going ?***
  - ***How do I get there ?***

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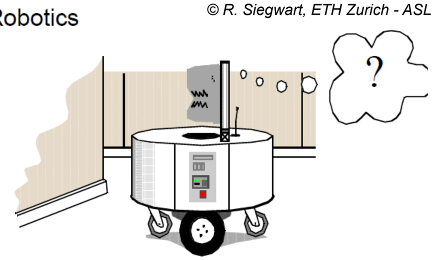
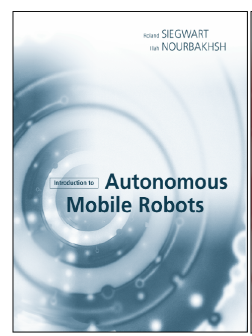
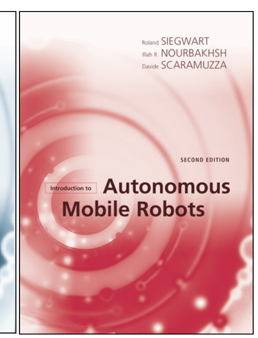


- To answer these questions the robot has to
  - have a model of the environment (given or autonomously built)
  - perceive and analyze the environment
  - find its position within the environment
  - plan and execute the movement
- This course will deal with Locomotion and Navigation (Perception, Localization, Planning and Motion Generation)

Introduction to Autonomous Mobile Robots: Resources

- Slides and Exercises
  - http://www.asl.ethz.ch/education/master/mobile_robotics
- Lecture Notes:
  - **Introduction to Autonomous Mobile Robots**
    Roland Siegwart & Illah Nourbakhsh
    - Intelligent Robotics and Autonomous Agents series
    - The MIT Press
    - Massachusetts Institute of Technology
    - Cambridge, Massachusetts 02142
    - ISBN 0-262-19502-X
  - http://www.mobilerobots.org





Introduction to Autonomous Mobile Robots: From Manipulators to Mobile Robots

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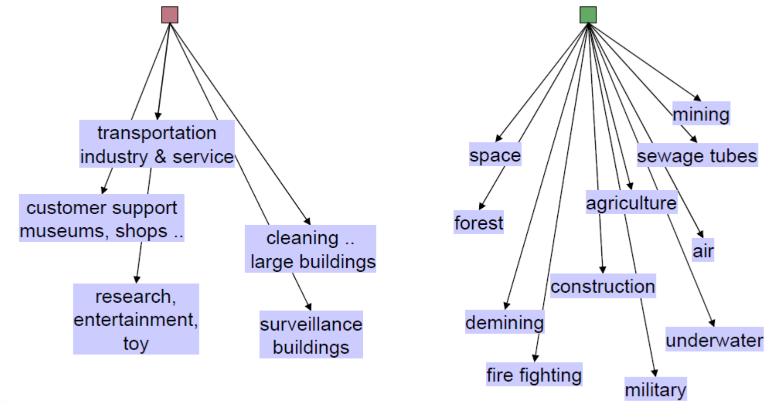
Introduction to Autonomous Mobile Robots: Applications of Mobile Robots



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Introduction to Autonomous Mobile Robots: Automatic Guided Vehicles

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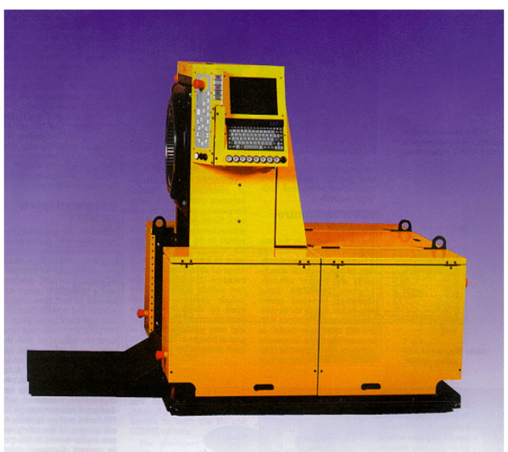

- Newest generation of Automatic Guided Vehicle of VOLVO used to transport motor blocks from on assembly station to an other. It is guided by an electrical wire installed in the floor but it is also able to leave the wire to avoid obstacles. There are over 4000 AGV only at VOLVO's plants.

Introduction to Autonomous Mobile Robots: HELPMATE

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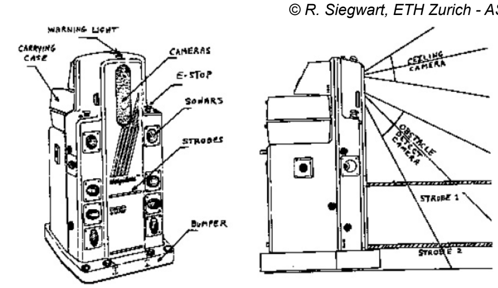

- HELPMATE is a mobile robot used in hospitals for transportation tasks. It has various on board sensors for autonomous navigation in the corridors. The main sensor for localization is a camera looking to the ceiling. It can detect the lamps on the ceiling as reference (landmark). http://www.ntplx.net/~helpmate/

Introduction to Autonomous Mobile Robots: BR700 Cleaning Robot

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- BR 700 cleaning robot developed and sold by Kärcher Inc., Germany. Its navigation system is based on a very sophisticated sonar system and a gyro. http://www.kaercher.de

Introduction to Autonomous Mobile Robots: ROV Tiburon Underwater Robot

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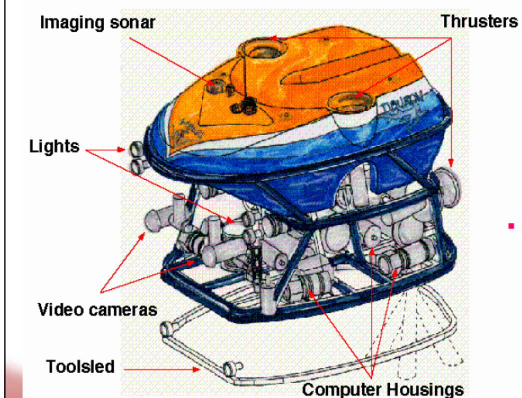
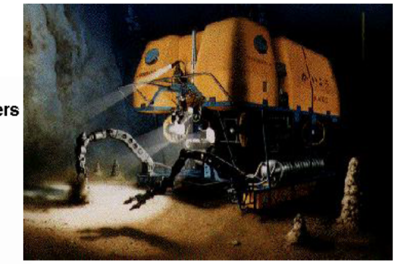
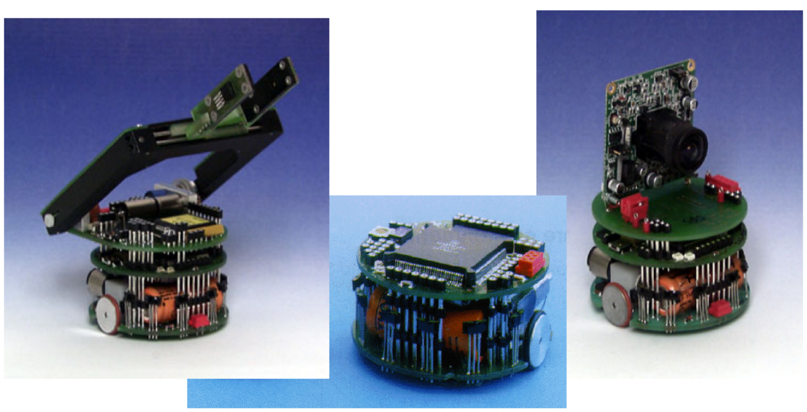




- Picture of robot ROV Tiburon for underwater archaeology (teleoperated)- used by MBARI for deep-sea research, this UAV provides autonomous hovering capabilities for the human operator.

Introduction to Autonomous Mobile Robots: Khepera Robot



- KHEPERA is a small mobile robot for research and education. It sizes only about 60 mm in diameter. Additional modules with cameras, grippers and much more are available. More then 700 units have already been sold (end of 1998). http://diwww.epfl.ch/lami/robots/K-family/ K-Team.html

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Introduction to Autonomous Mobile Robots: Forester Robot

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- Pulstech developed the first 'industrial like' walking robot. It is designed moving wood out of the forest. The leg coordination is automated, but navigation is still done by the human operator on the robot. http://www.plustech.fi/

Introduction to Autonomous Mobile Robots: Robots for Inspection

- HÄCHER robots for sewage tube inspection and reparation. These systems are still fully teleoperated. http://www.haechler.ch

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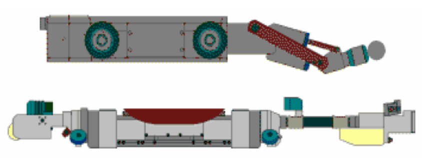
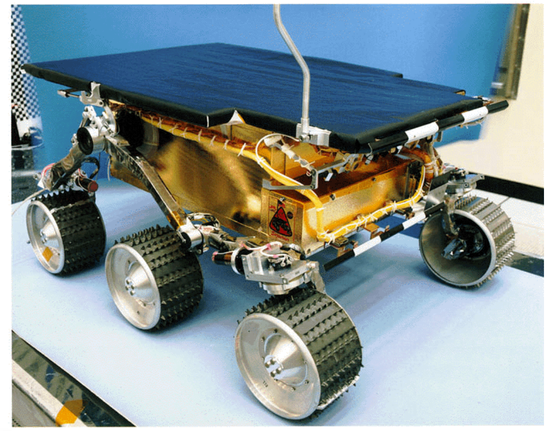


- Picture of Pioneer, the teleoperated robot that is supposed to explore the Sarcophagus at Chernobyl

Introduction to Autonomous Mobile Robots: Sojourner- First Robot on Mars



Sojourner was used during the Pathfinder mission to explore the mars in summer 1997. It was nearly fully teleoperated from earth. However, some on board sensors allowed for obstacle detection. http://ranier.oact.hq.nasa.gov/telerobotics_page/telerobotics.shtm

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Introduction to Autonomous Mobile Robots: General Control Scheme for Mobile Robot Systems

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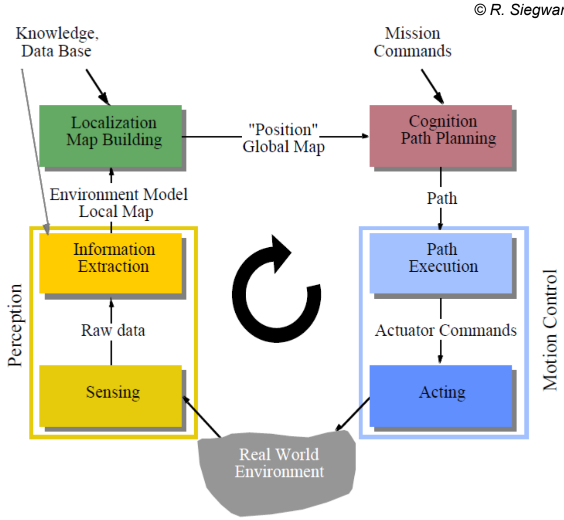

Mobile Robot Locomotion

- How do I get there?

Mobile Robot 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)

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Mobile Robot Locomotion Locomotion Concepts

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- 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***

Mobile Robot Locomotion: Biped Walking

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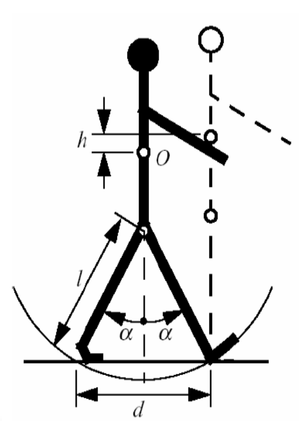
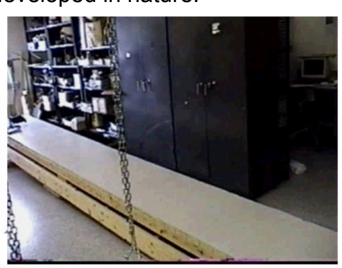


- Biped walking mechanism
  - not to far from real rolling.
  - rolling of a polygon with side length equal to the length of the step.
  - the smaller the step gets, the more the polygon tends to a circle (wheel).
- However, fully rotating joint was not developed in nature.



Mobile Robot Locomotion: Walking or Rolling?

- number of actuators
- structural complexity
- control expense
- energy efficient
  - terrain (flat ground, soft ground, climbing..)
- movement of the involved masses
  - walking / running includes up and down movement of COG
  - some extra losses

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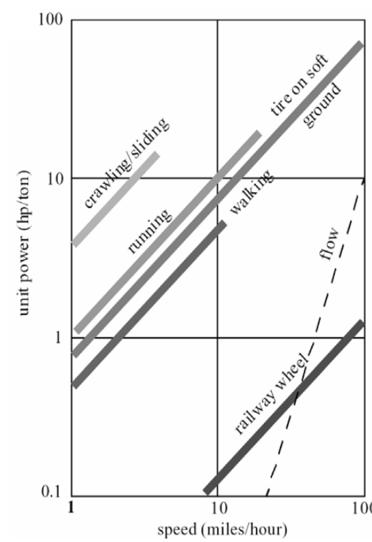

Mobile Robot Locomotion: Characterization of Locomotion Concept

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- Locomotion
  - physical interaction between the vehicle and its environment.
- Locomotion is concerned with *interaction forces*, and the *mechanisms* and *actuators* that generate them.
- The most important issues in locomotion are:

- 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 Robot Locomotion: Mobile Robots with Legs (Walking Machines)

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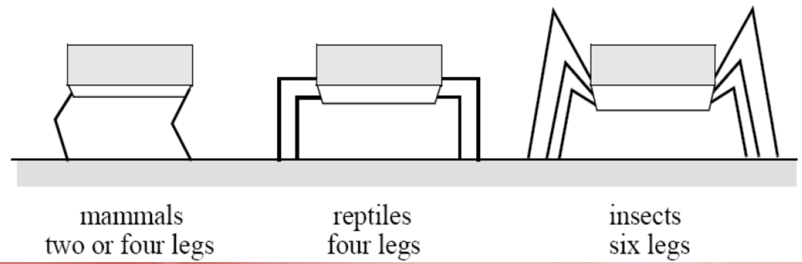
- The fewer legs the more complicated becomes locomotion
  - Stability - at least three legs are required for static stability
- During walking some legs are lifted
  - thus loosing stability?
- For static walking at least 6 legs are required
  - babies have to learn for quite a while until they are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



Mobile Robot Locomotion: Number of Joints of Each Leg → Degrees of Freedom

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- A minimum of two 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
- Three DOF for each leg in most cases
- Fourth DOF for the ankle joint
  - might improve walking
  - however, additional joint (DOF) increase the complexity of the design and especially of the locomotion control.

Mobile Robot Locomotion: Legs with 3 DoF

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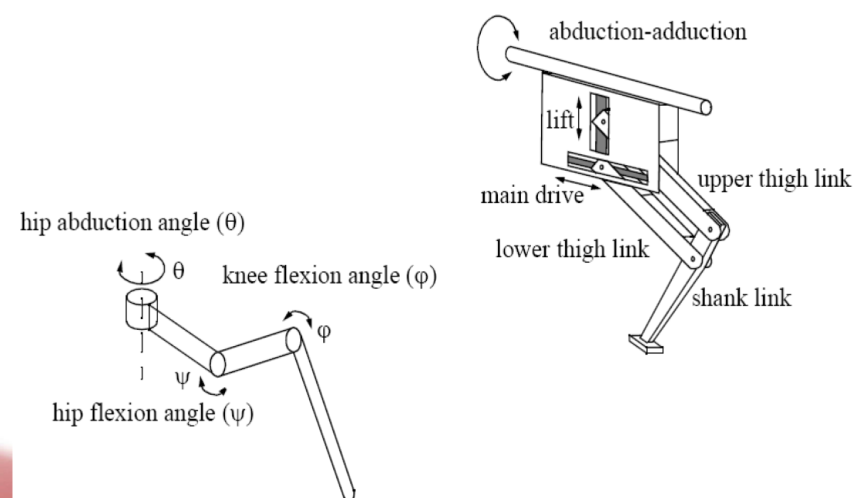


Mobile Robot Locomotion: Number of Distinct Event Sequences (Gaits)

- The gait is characterized as the distinct 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:

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

- For a robot with 6 legs (hexapod) N is already

$$N = 11! = 39'916'800$$

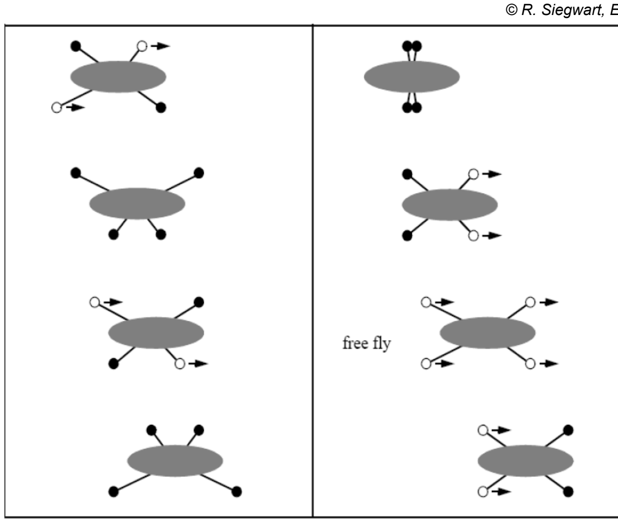
Mobile Robot Locomotion: Gaits for a Biped

- With two legs (biped) one can have four different states
  - 1) Both legs down
  - 2) Right leg down, left leg up
  - 3) Right leg up, left leg down
  - 4) Both leg up

● Leg down
○ Leg up

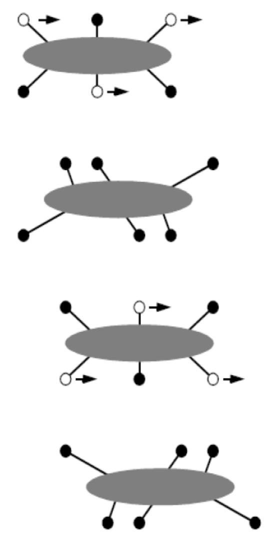
- A distinct event sequence can be considered as a change from one state to another and back.
- So we have the following $N = (2k-1)! = 6$ distinct event sequences (change of states) for a biped:

Mobile Robot Locomotion: Gaits with 4 Legs



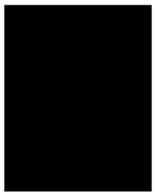
Changeover Walking Galloping

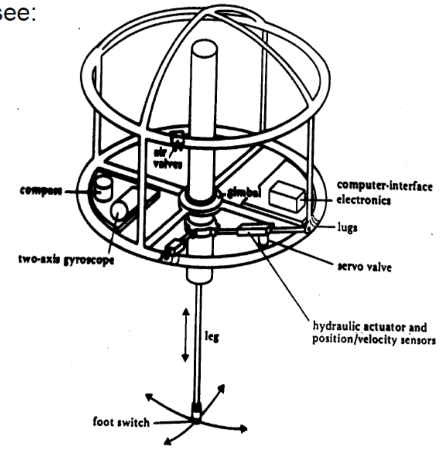
Mobile Robot Locomotion: Gait with 6 Legs



Mobile Robot Locomotion: Examples of Walking Machines

- No industrial applications up to date, but a popular research field
- For an excellent overview please see:
  http://www.uwe.ac.uk/clawar/





The Hopping Machine at MIT

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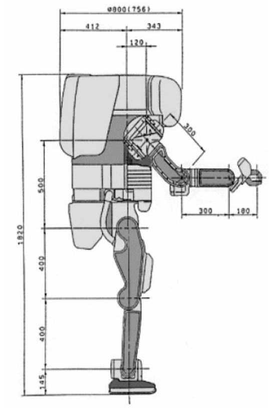
Mobile Robot Locomotion: Humanoid Robots

- P2 from Honda, Japan
  - Maximum Speed: 2 km/h
  - Autonomy: 15 min
  - Weight: 210 kg
  - Height: 1.82 m
  - Leg DOF: 2x6
  - Arm DOF: 2x7

Honda P3



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Mobile Robot Locomotion: Bipedal Robots

- Leg Laboratory from MIT

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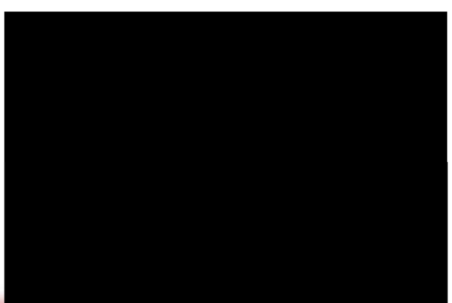
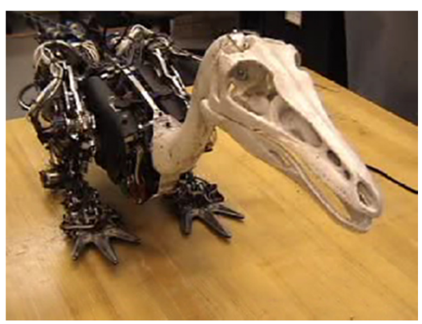
  - Spring Flamingo the bipedal running machine
  - "Troody" Dinosaur like robot





Mobile Robot Locomotion: Walking Robots with Four Legs (Quadruped)

- Artificial Dog Aibo from Sony, Japan

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Mobile Robot Locomotion: “Running” Robots with Four Legs (Quadruped)

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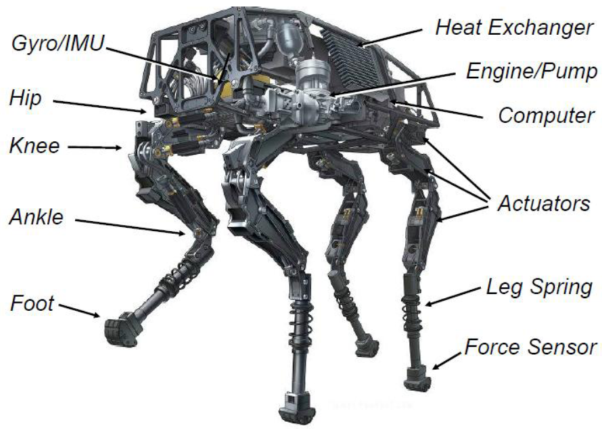
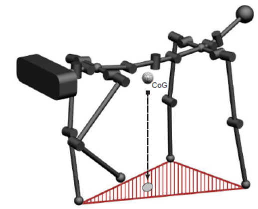
- Boston Dynamics Big Dog



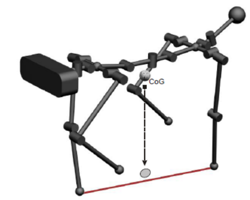
Mobile Robot Locomotion: Dynamic Walking vs. Static Walking

- **Statically stable**



  - Bodyweight supported by at least three legs
  - Even if all joints ‘freeze’ instantaneously, the robot will not fall
  - safe ↔ slow and inefficient

- **Dynamic walking**



  - The robot will fall if not continuously moving
  - Less than three legs can be in ground contact
  - fast, efficient ↔ demanding for actuation and control

Mobile Robot Locomotion: Walking Robots with Six 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

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Mobile Robot Locomotion: Walking Robots with Six Legs (Hexapod)

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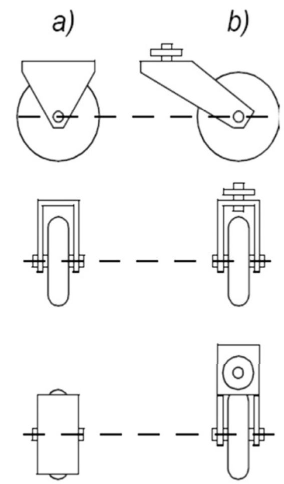
- Lauron II, University of Karlsruhe
  - Maximum Speed: 0.5 m/s
  - Weight: 6 kg
  - Height: 0.3 m
  - Length: 0.7 m
  - No. of legs: 6
  - DOF in total: 6*3
  - Power Consumption: 10 W

Mobile Robot Locomotion:
Mobile Robots with Wheels

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

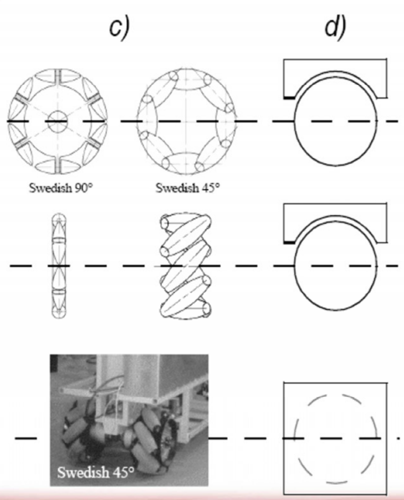
Mobile Robot Locomotion:
The Four Basic Wheels Types

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



Mobile Robot Locomotion:
The Four Basic Wheels 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

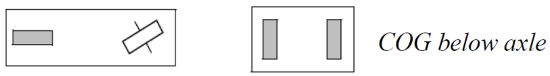


Mobile Robot Locomotion:
Characteristics of Wheeled Robots and Vehicles

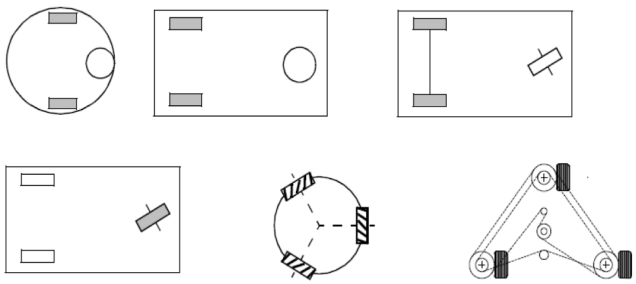
- Stability of a vehicle is be guaranteed with 3 wheels
  - center of gravity is within the triangle with is formed by the ground contact point of the wheels.
- Stability is improved by 4 and more wheel
  - however, this arrangements are hyperstatic and require a flexible suspension system.
- Bigger 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.

Mobile Robot Locomotion: Different Arrangements of Wheels

- Two wheels



- Three wheels



Omnidirectional Drive   Synchro Drive

Mobile Robot Locomotion: Cye- Two Wheel Differential Drive Robot

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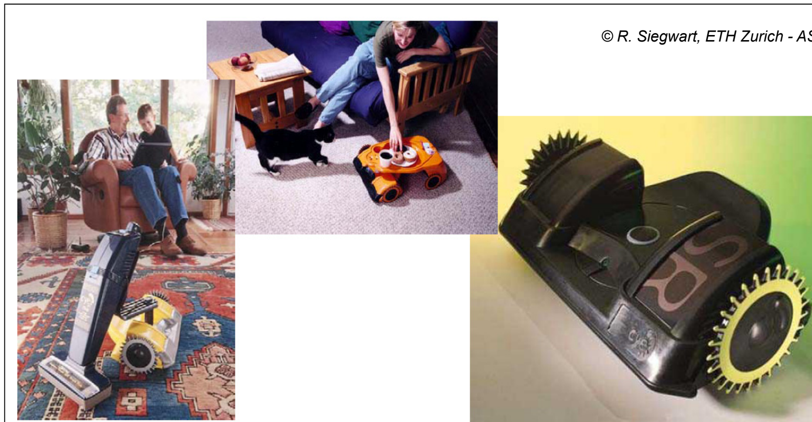

- Cye, a commercially available domestic robot that can vacuum and make deliveries in the home, is built by Probotics, Inc.

Mobile Robot Locomotion: Synchro Drive

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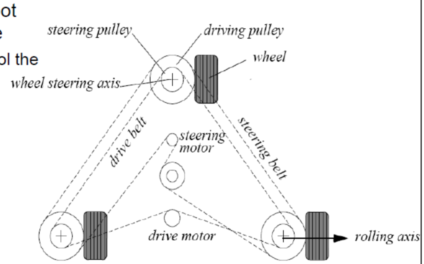
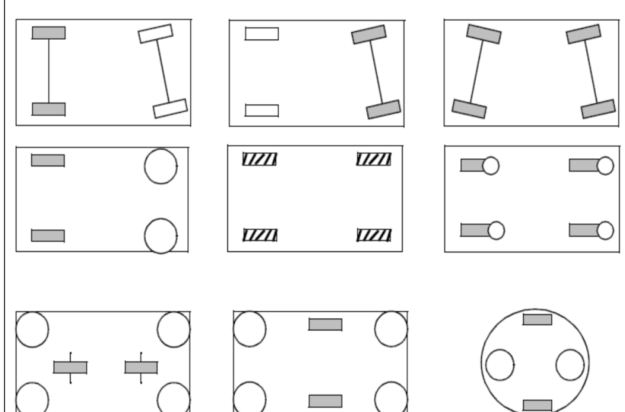
- All wheels are actuated synchronously by one motor
  - defines the speed of the vehicle
- All wheels steered synchronously by a second motor
  - sets the heading of the vehicle
- The orientation in space of the robot frame will always remain the same
  - It is therefore not possible to control the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



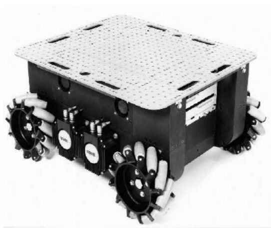
Mobile Robot Locomotion: Different Arrangements of Wheels

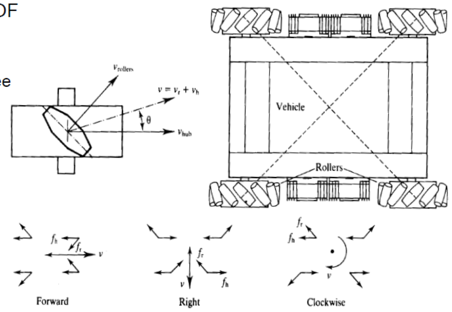
- Four wheels



Mobile Robot Locomotion: CMU Uranus- 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





Mobile Robot Locomotion: Wheeled Rovers- Concepts for Object Climbing

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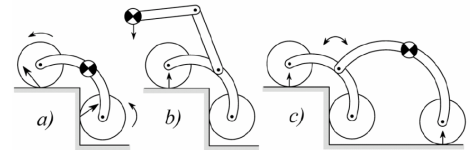
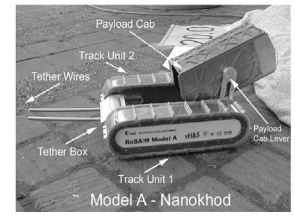


Purely friction based

Change of center of gravity (CoG)

Adapted suspension mechanism with passive or active joints



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

Mobile Robot Locomotion: Climbing with Legs- EPFL Shrimp

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- Passive locomotion concept
- 6 wheels
  - two boogies on each side
  - one fixed wheel in the rear
  - one front wheel with spring suspension
- length: 60 cm
- height: 20 cm

- Characteristics
  - highly stable in rough terrain
  - overcomes obstacles up to 2 times its wheel diameter