Mobile Robotics

Mobile robot classification continued

Lecturer

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http://sied.dis.uniroma1.it/ssrr07/

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Outline of today’s lecture

- What is a mobile robot?
- Mobile robot classification
  - Review of research achievements; challenging issues
- Mobile robot integration
  - Actuation; control system; sensor system; system hierarchy
- General research work on the mobile robot
  - Actuation and mechanical system; locomotion; kinematics; dynamics GUI; interface; other issues
- Application

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Mobile robot classification

- According to the environment in which they travel:
  - Land or home robots; Aerial robots and Underwater robots
- According to Kinematics
  - Legged robot; sliding frame robot; wheeled and chain-tracked robot
- According to the autonomous levels:
  - Autonomous or semi-autonomous modes
- According to applications
  - Service robots; edutainment robots; pure research prototypes; space robots; and civil or military robots

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Natural mobile mechanisms

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)

pp.14

According to kinematics

- Legged robots
  - One-legged to multiple-legged robots
- Wheeled robots
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- Sliding frame robots and snake-like robots



http://www.euron.org/resources/robotgallery.html

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Legged robots

- One leg
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- Four-legged-Quadruped
- Six-legged-Hexapod
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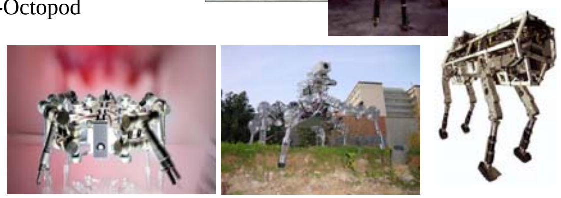

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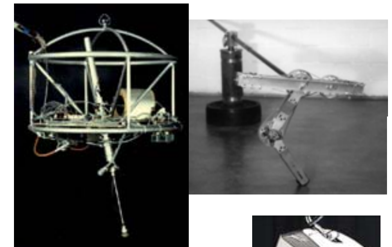
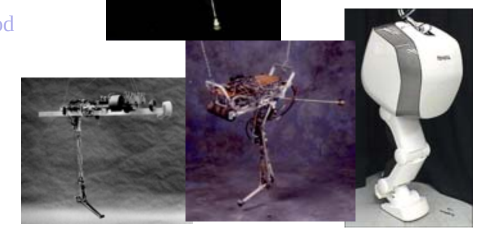
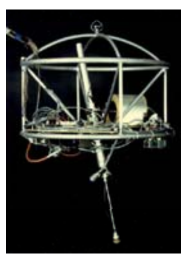




One leg mobile robot – Hopper

- The Leg Lab at the MIT Artificial Intelligence Lab is dedicated to studying legged locomotion and building dynamic legged robots. They are specialists in exploring the roles of balance and dynamic control, and interested in simulating and building creatures which walk, run, and hop like their biological counterparts.
- Built to show that actively balanced dynamic locomotion could be accomplished with simple control algorithms.
- It hopped in place, traveled at a specified rate, followed simple paths, and maintained balance when disturbed.



3D One-Leg Hopper (1983-1984)

http://www.ai.mit.edu/projects/leglab/robots/robots.html

One leg mobile robot – Monopode

- Toyota has developed a 3.3 feet high monopode robot (a robot with just one leg) that can **JUMP LIKE A HUMAN** (a human with one leg...) without the use of a motor using a special joint in its "toe."
- The robot was developed to prototype the jumping action required for running, which will presumably be put to use in future bipedal robots.

http://www.therawfeed.com/2006/09/toyotas-one-legged-robot-great-leap.html

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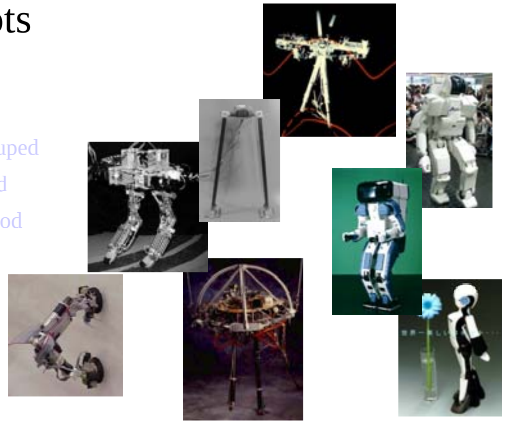
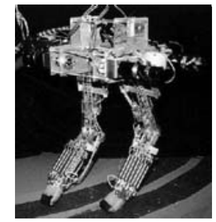


Two-legged mobile robot – Spring Turkey

- Spring Turkey was designed and built by Peter Dilworth and Jerry Pratt in 1994.
- It is a planar bipedal walking robot. This robot was developed as an experimental platform for implementing
  - Force control actuation techniques, particularly Series Elastic Actuation
  - Motion description and control techniques, particularly Virtual Model Control
  - Various walking algorithms



Spring Turkey (1994-1996)

http://www.ai.mit.edu/projects/leglab/robots/robots.html

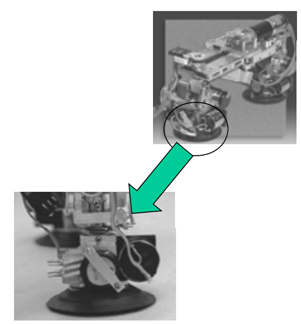
Two-legged mobile robot – 3D Biped

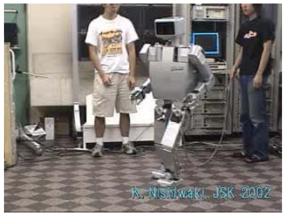
3D Biped (1989-1995)

http://www.ai.mit.edu/projects/leglab/robots/robots.html

Two-legged mobile robot–Smart biped robot

- Miniature robot (cm^2): 52.5
- Lightweight: <500g
- Vacuum suction
- Moves very slowly
- Not enough sensors on board





Sony robots

Others

Legged robots

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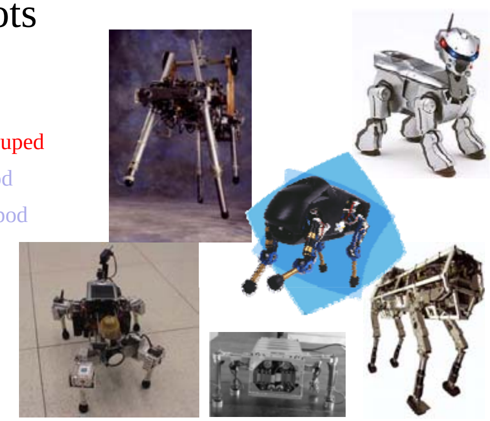

Four-legged mobile robots – Aibo

- Sony Aibo
  - 25 cm long
  - With camera, microphone and other sensors
  - With communication interface

http://support.sony-europe.com/aibo/

Four-legged mobile robot – Quadruped

- The Quadruped was used to explore running on four legs in 1984.
- It can trot, pace, bound, and do several transitions between gaits.
- Only quadruped gaits that use the legs in pairs: trotting (diagonal legs as pairs), pacing (lateral pairs), and bounding (front pair and rear pair).
- By restricting consideration to the pair gaits, the control of the Quadruped was reduced to the control of an equivalent *virtual* biped.

Quadruped (1984-1987)

http://www.ai.mit.edu/projects/leglab/robots/robots.html

Four-legged mobile robot – Little dog

- A quadruped robot for research on learning locomotion to probe the fundamental relationships among motor learning, dynamic control, perception of the environment, and rough terrain locomotion.
- Four legs with a large range of motion and workspace, each powered by three electric motors.
- Joint angles, motor currents, body orientation and foot/ground contact.
- Control programs access the robot through the Boston Dynamics Robot API. Onboard lithium polymer batteries allow for 30 minutes of continuous operation without recharging.

Little dog

http://www.bostondynamics.com/content/sec.php?section=LittleDog

Others

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Four-legged mobile robot – Big dog

- BigDog is the alpha male of the Boston Dynamics family of robots.
- Walks, runs, and climbs on rough terrain and carries heavy loads.
- Powered by a gasoline engine that drives a hydraulic actuation system.
- Articulated like an animal's, and has compliant elements that absorb shock and recycle energy from one step to the next.
- The size of a large dog or small mule, with a length of 1 m, a height of 0.7 m and a weight of 75 kg.

Big dog

http://www.bostondynamics.com/content/sec.php?section=BigDog

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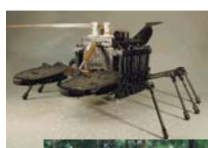






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Six-legged mobile robot – RiSE

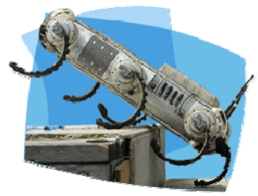
- A small robot that can climb vertical terrain such as walls, trees and fences, which is funded by the DARPA Defense Sciences Office.
- 0.25 m long, weighs 2 kg, and travels 0.3 m/s.
- Leg powered by two electric motors. Feet have claws, micro-claws or sticky material, depending on the climbing surface.
- An inertial measurement unit, joint position sensors for each leg, leg strain sensors and foot contact sensors.
- Dry adhesion to climb sheer vertical surfaces such as glass and metal.
- The project is a cooperation between the University of Pennsylvania, Carnegie Mellon, Berkeley, Stanford, and Lewis and Clark University.

RiSE

http://www.bostondynamics.com/content/sec.php?section=RiSE

Six-legged mobile robot – RHex

- A man-portable robot with extraordinary rough terrain mobility.
- Climbs over rock fields, mud, sand, vegetation, railroad tracks, telephone poles and up steep slopes and stairways; it also can swim when the body is sealed.
- Controlled remotely from an operator control unit at distances up to 600 meters.
- A video uplink provides front and rear views from onboard cameras.
- Uplink navigational data from onboard compass and GPS and from payload sensors.



RHex

http://www.bostondynamics.com/content/sec.php?section=RHex

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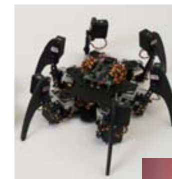

http://www.lynxmotion.net/viewtopic.php?t=3242&sid=9d4e32ee3752998cadb1b2d399e1933f

Eight-legged mobile robot – Halluc II

- A robotic vehicle with eight wheels and legs designed to drive or walk over rugged terrain; it was developed by researchers at the Chiba Institute of Technology
- Aims to move sideways, turn around in place and drive or walk over a wide range of obstacles.
- The researchers hope the robot's abilities will help out with rescue operations, and they would like to see Halluc II's technology put to use in transportation for the mobility-impaired.

Halluc II

http://www.furo.org/robot/halluc2/index.html

Eight-legged mobile robot – Scorpion

- It is an eight-legged walking robot for hazardous outdoor-terrain. It uses a biomimetic control concept which allows a very flexible, robust walking behavior in various terrains.
- Its gaits are based on research on walking patterns of real scorpions.
- It can be controlled in an intuitive way, an optional voice control, and a data glove.
  - http://www.dfki-bremen.de/robotik/

Scorpion

@NASA
http://www.nasa.gov/centers/ames/research/exploringtheuniverse/scorpion_robot.html

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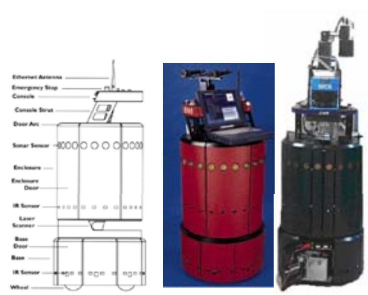
http://www.euron.org/resources/robotgallery.html

Wheeled robots

Wheeled robots – B21

- B21 Robot
  - A sophisticated mobile robot with up to three Intel Pentium processors on board.
  - It has different kinds of on-board sensors for high performance navigation tasks.



http://www.cercia.ac.uk/our_services/facilities/b21.php

Wheeled robots – TASER

- Taser
  - Service-robot of the University of Hamburg
  - Mobile platform with differential drive
  - Two Mitsubishi PA10-6C manipulators
  - Two 3-finger robotic hands
  - Stereovision camera head
  - Omni-directional vision system
  - Two SICK laser range finders
  - Pentium 4 control PC
  - Wireless LAN communication

@TAMS

Wheeled robots – John Deere R-Gator

- A versatile and rugged platform capable of taking on a wide variety of critical unmanned missions, such as a perimeter guard, unmanned scout, “point man,” supply carrier and more.
- Combining the field-proven technologies, navigation and obstacle detection technologies jointly developed for critical missions.
- Offering the chance to evaluate unmanned vehicle technology advantages in numerous operational scenarios.
- In autonomous mode, numerous sensors to detect obstacles and guide the vehicle. With a single switch, the operator can transition to manual mode and drive the vehicle like a car.

http://www.irobot.com/sp.cfm?pageid=141

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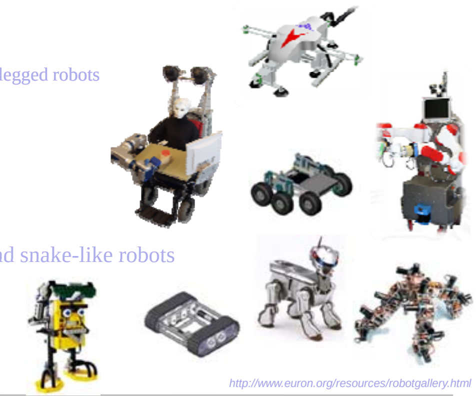

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Chain-tracked robots

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http://www.irobot.com/sp.cfm?pageid=150

Chain-tracked robots – OmniTread

- Use of pneumatic bellows for joint actuation. Bellows are powerful, naturally compliant, and take up minimal space.
- Maximal coverage of all sides of all segments with extra wide moving tracks.
- Unique pneumatic control method allows simultaneous proportional control of stiffness and joint angles.
- The "drive shaft spine" is powered by a single electric motor in the center segment. The spine runs through the center of all segments and provides torque to all tracks.

http://www.engin.umich.edu/research/mrl/00MoRob_6.html

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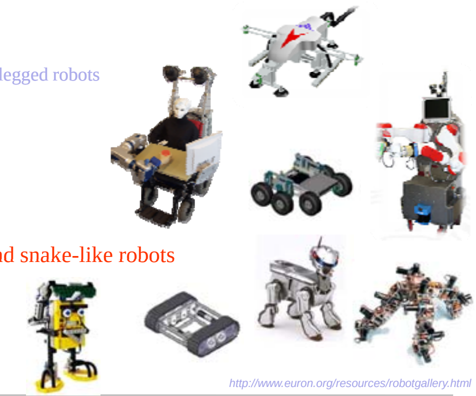

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Sliding-frame robots

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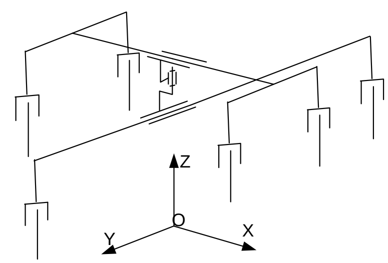
Sliding-frame robots



Snake-like robots

Snake-like robots – ACM-R5

- An amphibious snake-like robot that can operate both on the ground and in water undulating its long body, developed by Tokyo Institute of Technology in Japan.
- Equipped with paddles and passive wheels. To generate propulsive force by undulation, the robot needs a resistance property as it glides freely in the tangential direction but cannot move straight ahead.
- The control system of ACM-R5 is an advanced one. Each joint unit has a CPU, a battery, and motors, so that it can operate independently.

Table. 1 ACM-R5 (9 units) specifications

D.O.F	18
Size	1750 (length) x 80 (diameter) [mm]
Weight	7.5 [kg]
Torque of joint (Max.)	9 [Nm]
Speed of joint (Max.)	70 [deg/s]

http://www-robot.mes.titech.ac.jp/robot/snake/acm-r5/acm-r5_e.html

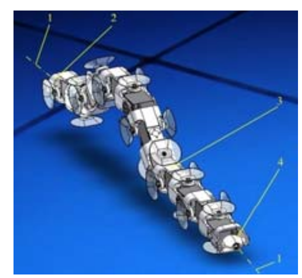
Snake robots – Anna Konda

- Anna Konda was developed in order to demonstrate the Snake-fighter concept. The robot is one of the biggest and strongest snake robot in the world and also the first water hydraulic snake robot ever constructed.
- Technical data
  - Length: 3 m
  - Weight: 75 kg
  - Number of DOFs: 20
  - Angular flexion in each joint: +/- 33 degrees
  - Actuators: Water hydraulic cylinders
  - Max system pressure: 100 bar (1450 PSI)
  - Max torque (at 100 bar): 300 Nm

Anna Konda fire-fighting snake robot

ZC-I modular climbing caterpillar

- Quick-to-assemble mechanical structure and low-frequency vibrating passive attachment principle.
- Active joints actuated by RC servos endow the connecting modules with the ability of changing shapes in two dimensions.
- Various locomotion capabilities will be achieved based on an inspired control model to produce rhythmic motion.



Picture taken from a 3D-animation of the planned robotic caterpillar in a variety of postures.

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Challenging issues

- What skills do mobile robots need?
- Elements of mobile robot autonomy
- Control scheme
- Navigation
- Localization
- Power supply

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What skills do mobile robots need?

- **In general**
  - The autonomous mobile robot will move from the starting position to the target position to complete given tasks once or regularly.

Houxiang Zhang

What skills do mobile robots need?

- **Navigation**:
  - *Where am I going?*
    - Planning and Mapping
  - *Where am I?*
    - Localization
  - *How do I get there?*
    - Recognition and modeling;
    - Object detection and avoidance,
- **Manipulation**:
  - *How do I change that?*
    - Interacting with objects/environment

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Elements of mobile robot autonomy

- Locomotion capability
- Sensory perception
- Knowledge representation
- Planning
- Autonomy
- Collaboration

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Elements of mobile robot autonomy

- Locomotion capability
- Sensory perception
  - The robots have to sense what is in their environment in order to navigate in it, detect hazards, and identify goals. Sensor fusion is an important capability, as no single sensor will be able to identify or classify all aspects of the concerned area. These different goals are represented by a collection of different sensory signatures.
- Knowledge representation
- Planning
- Autonomy
- Cooperation

Elements of mobile robot autonomy

- Locomotion capability
- Sensory perception
- Knowledge representation
  - Knowledge representation is the next level. It encompasses the robot' s ability to model the world, using both a prior information and newly acquired information. Ideally, this would provide humans with a map of the environment they have explored. The environment that the robots operate in is three-dimensional, hence they should reason in and be able to map in three dimensions.
- Planning
- Autonomy
- Cooperation

Elements of mobile robot autonomy

- Locomotion capability
- Sensory perception
- Knowledge representation
- Planning
- Autonomy
  - The robots are designed to operate with humans. The level of interaction may vary significantly, depending on the robot's design and capabilities, or on the circumstances. Pure tele-operation is not a desirable mode for the robot's operation. The human should provide the robot with high level commands, such as "go to the room on the left" rather than joystick the robot in that direction.
- Cooperation

Elements of mobile robot autonomy

- Locomotion capability
- Sensory perception
- Knowledge representation
- Planning
- Autonomy
- Cooperation
  - Usually the complicated task is based on the cooperation in a team, such as a rescue and search implementation. The given targets will be assigned separately. Every robot should communicate with the others and perform distributed activities.

Challenging issues

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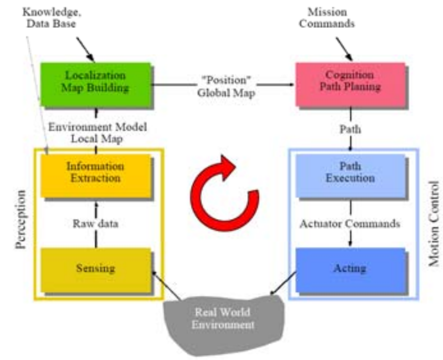
Control scheme



Challenging issues

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Navigation: planning and navigating?

- **Navigation**:
  - is the process of planning, recording, and controlling the movement of a craft or vehicle from one place to another.
    - *http://en.wikipedia.org/wiki/Navigation#_note-bow799*
  - is the first key issue in the mobile robotic technology. The difficulty depends on the manipulation or tasks which the robot will implement.

Navigation: motion difficulty

- Random movement:
  - Obstacle detection
  - Collision avoidance
  - Collision prediction
- Fixed goal:
  - Go to a point or series of points
- CCM (Complete coverage movement):
  - Explore or cover an area
  - Try not to backtrack too much
- Dynamic goal:
  - Go to a possible moving point
  - Specify the goal as an abstract concept

Source: Prof. Dr. Yi Guo, EE631: Cooperating Autonomous Mobile Robots (Fall 2006), Hoboken, NJ 07030, U.S.A

Navigation: review of robot navigation

- Early methods:
  - Sense, plan, act
  - Sensor analysis took time: attempted to build high-level representations
  - Planning was deliberate and took time
  - Actions slow
- Reactive methods:
  - Sense-decide-act
  - Simplify the sensing: use a lower level representation
  - Simplify the decision-making: use sub-symbolic or simple computation
  - Let the decision-making and analysis work in parallel
  - Combine the resulting “behaviors” in a useful way
  - Actions are much faster

Source: Prof. Dr. Yi Guo, EE631: Cooperating Autonomous Mobile Robots (Fall 2006), Hoboken, NJ 07030, U.S.A

Navigation methods

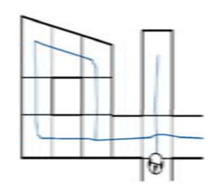
- Combined systems:
  - Layer 1: behaviors reacting to sensor stimulus
  - Layer 2: combinations of behaviors and goals
  - Layer 3: high-level sensor analysis and planning

Combined systems seem to offer the most promise for real world robots

Source: Prof. Dr. Yi Guo, EE631: Cooperating Autonomous Mobile Robots (Fall 2006), Hoboken, NJ 07030, U.S.A

Navigation classifications

- Geometric methods
  - Geometric maps are composed of the union of simple geometric primitives
    - 2D map according to: points, lines, line segments and polylines(piecewise linear curves), circles and arcs of circles, polynomials, splines
    - 3D map according to: points, planar surfaces, surface patch networks, circles and ellipsoids, splinesurfaces
- Topological methods
  - Road Map, graph construction
  - Cell decomposition
  - Potential field



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Navigation: a circle inside

If we have a map:
We can localize!

NOT THAT SIMPLE!

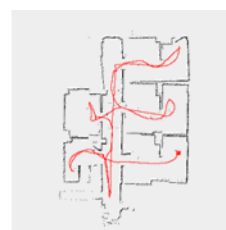
If we can localize:
We can make a map!

Challenging issues

- What skills do mobile robots need?
- Elements of mobile robot autonomy
- Control scheme
- Navigation
- Localization
- Power supply

Localization

- **Landmark**:
  - Using landmarks to calculate the position in a given map
- **Sensor feedback**:
  - Global and local perception
- **SLAM (Simultaneous localization and mapping)**:
  - Global and local perception

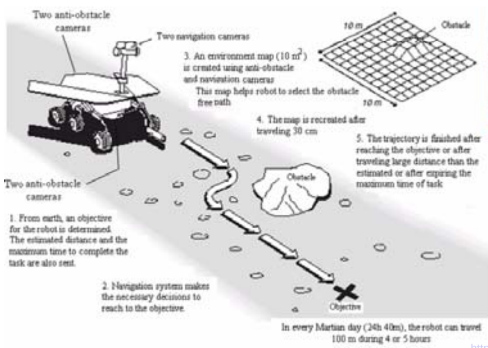


Laser-based wall map (CMU)

Minerva's ceiling map

Source: Prof.Christopher Rasmussen, CIS 849: Autonomous Robot Vision, University of Delaware, U.S.A.

Space exploration robots – Sojourner



Mars Rover

http://marsrover.nasa.gov/home/index.html

Challenging issues

- What skills do mobile robots need?
- Elements of mobile robot autonomy
- Control scheme
- Navigation
- Localization
- Power supply

Power supply

- Power supply is the bottleneck of autonomous mobility

Thanks for your attention!

Any questions?

Volksbot

http://www.volksbot.de/img/robots/volksbots.jpg