Introduction to Mobile Robotics

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Robotics: an inter-disciplinary field

Robotics overlaps or has close ties with many fields, including:

- Artificial Intelligence
- Computer Vision
- Machine Learning / Neural Networks
- Cognitive Science
- Electronic / Mechanical Engineering

In fact the differentiation between these fields is sometimes artificial.

What is a Robot?

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A physically-embodied, artificially intelligent device with sensing and actuation.

- It can sense. It can act.
- It must think, or process information, to connect sensing and action.
- Is a washing machine a robot? Most people wouldn't say so, but it does have sensing, actuation and processing.

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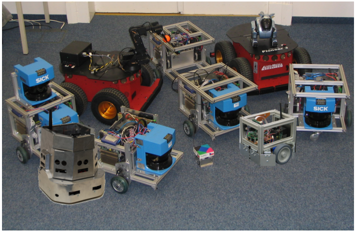
- Is a washing machine a robot? Most people wouldn't say so, but it does have sensing, actuation and processing.
- A possible distinction between appliance and robot (David Bisset): whether the workspace is physically inside or outside the device.
- The cognitive ability required of a robot is much higher: the outside world is complex, and harder to understand and control.

Autonomy

- Teleoperated - fully controlled (all outputs) by a human.
- Semi-teleoperated - a human defines a particular goals, a robot performs some control actions.
- Autonomous - a robot performs a defined goal (by a human or other system) without continuous human guidance.

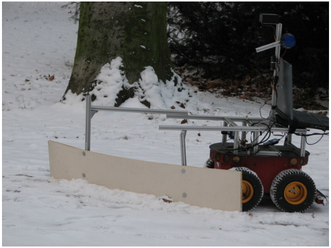
Our focus: mobile robots

- A mobile robot needs actuation for locomotion and sensors for guidance.
- Ideally untethered and self-contained: power source, sensing, processing on-board



The tree key questions in Mobile Robotics

- Where am I?
- Where am I going?
- How do I get there?



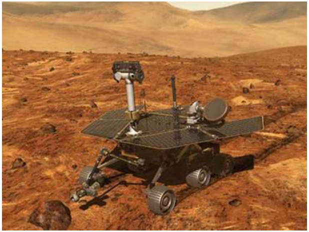
- To answer these questions the robot has to
  - have a model of the environment (given or autonomously built),
  - perceive and analyze the environment,
  - find its position/situation within the environment,
  - plan and execute the movement.

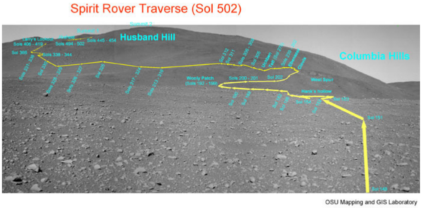
Course outline

- Monday – Lecture
  - Introduction – applications, architectures, kinematics, sensors
  - Mapping – intro to probability, grid maps, geometric representations, topological maps
- Tuesday – Lecture
  - Planning I – terms, configuration space
  - Planning II – roadmaps, potential fields, probabilistic methods
  - Bug algorithms
- Wednesday – Lecture
  - Localization I – taxonomy, continuous localization
  - Localization II – probabilistic methods, Bayes filter, models
- Thursday – Laboratories
  - Task definition, intro to Player/Stage and SyRoTek
  - Independent work in pairs!
- Friday – Laboratories
  - Independent work in pairs (cont.)
  - Presentation of the work done

Mobile robots: state of the art

Mars rovers Spirit and Opportunity (NASA)





- Both had successful missions on Mars in starting in late 2004. Spirit went 'silent' in March 2010; Opportunity is still operational and is exploring a crater currently.
- 9 cameras (Hazcams, Navcams, Pancams, microscopic).
- Remote human planning combined with local autonomy. Why?
- Increased autonomy as mission has progressed.
- See `http://marsrover.nasa.gov/home/`.

Mobile robots: state of the art

DARPA Grand Challenge 2005 winner ‘Stanley’ (Stanford University, USA)

- Completed 175 miles desert course autonomously in 6 hours 54 minutes.
- Guided along rough ’corridor’ by GPS.
- Road-following and obstacle avoidance using laser range-finders and vision.

Mobile robots: state of the art

DARPA Urban Challenge 2007 winner 'Boss' (Carnegie Mellon University, USA)

- Robots had to achieve extended missions in a mocked-up urban area, obeying traffic laws and avoiding other robots and cars.
- Much more sophisticated sensor suites than in desert challenge (lasers, cameras, radars) to achieve all-around awareness.

Mobile robots: state of the art

iRobot ‘Roomba’ Robot Vacuum Cleaner

- ‘Random bounce’ movement style with short-range IR sensing.
- Over 2 million units sold!
- Second generation and competing products are now aiming at precise navigation. e.g. Mint robot, Evolution Robotics: `http://www.mintcleaner.com/clean/`.

Mobile robots: state of the art

Supplying in a hospital, Motol, Prague

- Rederix automated delivery system
- Delivers beds, bedding, food, medical material
- Remote door opening, elevators control
- 16 distribution points, 400 goals, 500km/day
- Inductive rail, ultrasound sensors, bumpers

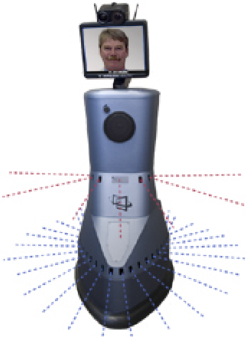
Mobile robots: state of the art

Robot companion

- Robot Pearl in Longwood Retirement Community
- Laser scanner, ultrasound sensors, map
- Reminding periodic activities (eating, hygiene, etc.)

Mobile robots: state of the art

Robots in hospital



- Robot RP-7, Touch Health's
- Communication patient ↔ doctor
- Mobile chassis, PC with display and cameras
- Tele-operated, information about a patient

Mobile robotics applications

- Field Robotics
    - Exploration (planetary, undersea, polar).
    - Search and rescue (earthquake rescue; demining).
    - Mining and heavy transport; container handling.
    - Military (unmanned aircraft and submarines, insect robots).
- Service Robotics
    - Domestic (Vacuum cleaning, lawnmowing, clearing the table...?).
    - Medical (helping the elderly, hospital delivery, surgical robots).
    - Transport (Autonomous cars).
    - Entertainment (Sony AIBO, QRIO, Lego Mindstorms, Robocup competition, many others).



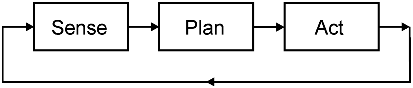


Cognitive robot architectures

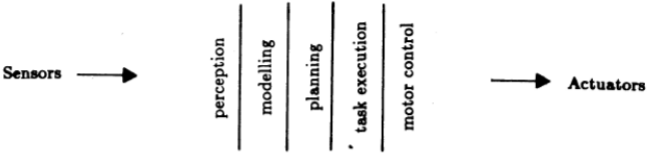
- Deliberative
- Reactive
  - Pure reactive
  - Subsumption architectures
  - Potential fields
- Hybrid

Deliberative control architecture

Hierarchical

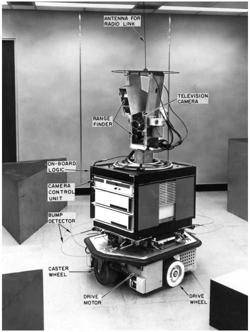


- Serial/horizontal architecture
- $\approx$ 1960: robotics labs at universities were an important play field for starting artificial intelligence
- Precise world model assumed



Shakey robot

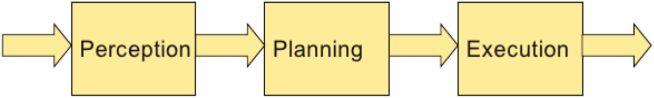
- Built at Stanford Research Institute in 1969.
- Focused on automated reasoning and knowledge representation (box pushing).
- STRIPS - Stanford Research Institute Problem Solver (1^{th} order predicate logic).
- On a very good day it could formulate and execute, over a period of hours, plans involving moving from place to place and pushing blocks to achieve a goal.



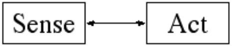
Deliberative control architecture

Criticism

- Modeling the world too hard and slow.
- Non-linear planning intractable (NP-complete).
- Feedback through world model cumbersome.
- Single chain mapping sensing to action.
- Very general $\rightsquigarrow$ poor at lots of tasks.
- Passing representations between modules is slow.

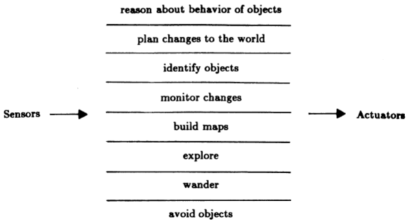


Reactive architectures



- No memory – no look-ahead reacts to the current environmental stimuli/ sensory information.
- Don't build world models, don't plan, use short feedback loops.
- Create many chains that maps sensing to action.
- Very specific $\rightsquigarrow$ good at one or two tasks.

D.MacFarland: "There are no general purpose animals... why should there be general purpose robots?"



Reactive architectures

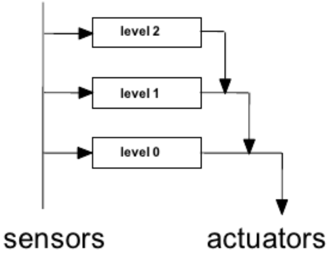
- Simplicity
- Economy.
- Computational tractability.
- Robustness against failure.
- Elegance.
- Agents without environment models must have sufficient information available from local environment.
- If decisions are based on local environment, how does it take into account non-local information (i.e., it has a "short-term" view).
- Difficult to make reactive agents that learn.
- Since behavior emerges from component interactions plus environment, it is hard to see how to engineer specific agents (no principled methodology exists).
- It is hard to engineer agents with large numbers of behaviors (dynamics of interactions become too complex to understand).

Subsumption architecture

- Build the system from bottom up
- Components are tasks achieving behaviors
- Components are executed in parallel
- Components are organized in layers
- Lowest layers handle most basic tasks
- Higher levels exploit the lower levels
- Each component has its tight connection between perception and action
- Bottom up design process

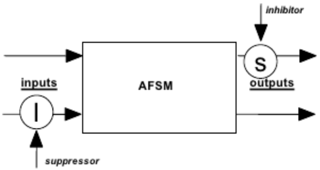
Subsumption layers

- First, we design, implement and debug layer 0.
- Next, we design layer 1
  - When layer 1 is designed, layer 0 is taken into consideration and utilized, its existence is subsumed (thus the name of the architecture).
  - As layer 1 is added, layer 0 continues to function.
  - Continue designing layers, until the desired task is achieved.



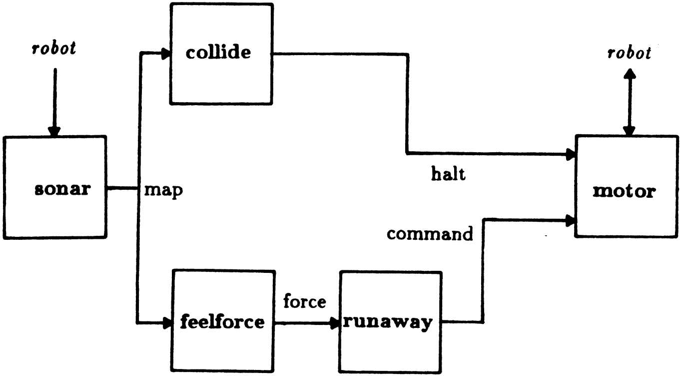
Suppression and Inhibition

- Higher layers can disable the ones below.
  - Avoid-obstacles can stop the robot from moving around.
- Layer 2 can either:
  - Inhibit the output of level 1 or
  - Suppress the input of level 1
- The process is continued all the way to the top level



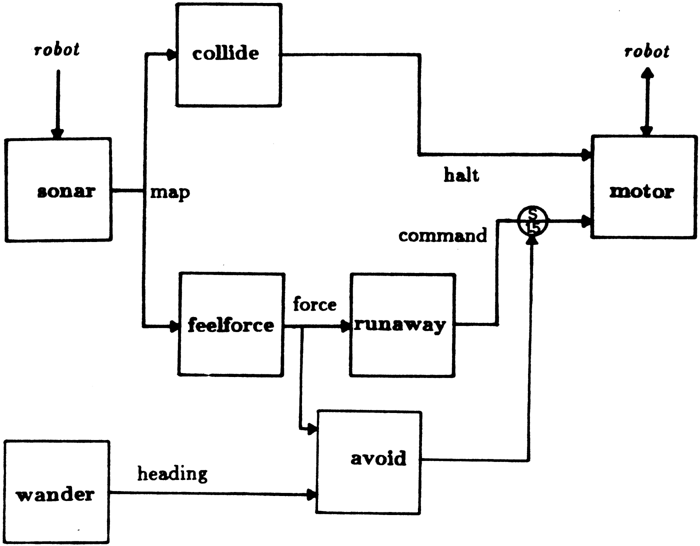
Subsumption architecture

Example



Subsumption architecture

Example



Mobile robot kinematics

- wheeled

Mobile robot kinematics

- wheeled 

Mobile robot kinematics

- wheeled  
- limbed

Mobile robot kinematics

- wheeled  
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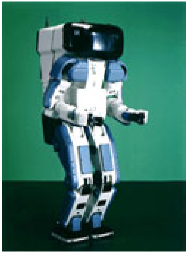


Mobile robot kinematics

- wheeled  
- limbed  

Mobile robot kinematics

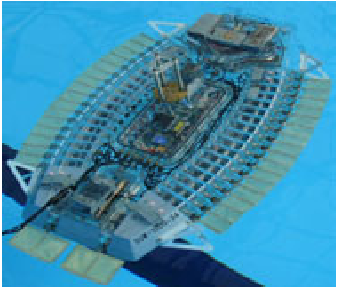
- wheeled  
- limbed   
- flying

Mobile robot kinematics

- wheeled  
- limbed   
- flying 

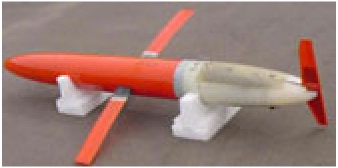
Mobile robot kinematics

- wheeled  
- limbed   
- flying  
- aquatic



Mobile robot kinematics

- wheeled  
- limbed   
- flying  
- aquatic 



Mobile robot kinematics

- wheeled  
- limbed   
- flying  
- aquatic  
- hybrid

Mobile robot kinematics

- wheeled  
- limbed   
- flying  
- aquatic  
- hybrid 

Mobile robot kinematics

- wheeled  
- limbed   
- flying  
- aquatic  
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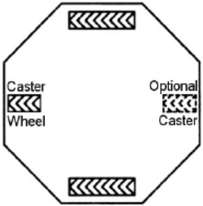
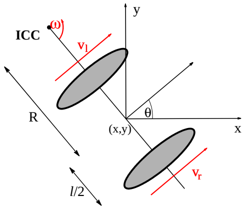
Wheeled robots - kinematics

Differential drive

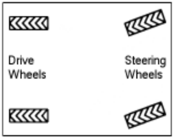




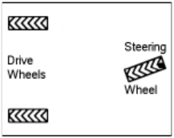
- Two motors, one per wheel: steering achieved by setting different speeds.
- Wheels run at equal speeds for straight-line motion.
- Wheels run at equal and opposite speeds to turn on the spot.
- Other combinations of speeds lead to motion in a circular arc.

Wheeled robots - kinematics

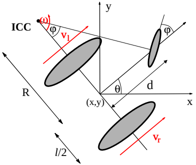
Ackermann steering



Car



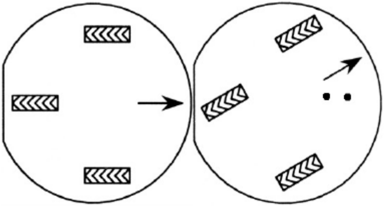
Tricycle

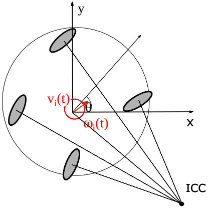


- Two motors: one to drive, one to steer.
- Cannot normally turn on the spot.
- Fixed speed and steering angle $\rightsquigarrow$ a circular path.
- With four wheels, need rear differential and variable (‘Ackerman’) linkage for steering wheels.

Wheeled robots - kinematics

Synchro drive





- Two motors: one rotates all wheels on mechanically coupled pivots; one drives them all at the same velocity.
- Robot body does not rotate (or needs another motor).

Wheeled robots - kinematics

Mecanum wheels

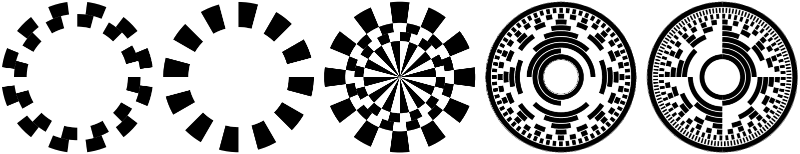
Sensing

- Sensing is usually divided into two categories:
    1. Proprioceptive sensing - 'self-sensing' of a robot's internal state.
    2. External sensing - of the world around a robot.
- . . . although sometimes the distinction is not completely clear (e.g. a magnetic compass would normally be considered proprioceptive sensing).
- Most mobile robots have various sensors, each specialized in certain tasks. Combining information from all of these is often called **sensor fusion**.

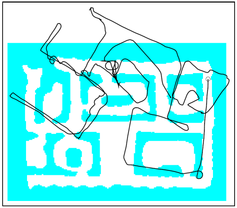
Dead Reckoning (optical encoders)

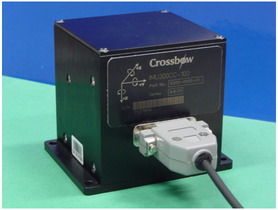


- Attached to a rotating object (motor, wheel)
- By measuring rotations it determines displacements, velocity, and acceleration
- 10-10000 pulses per revolution
- other principles: resolvers, optical correlation odometry (optical mouse), Doppler sensors



Heading sensors

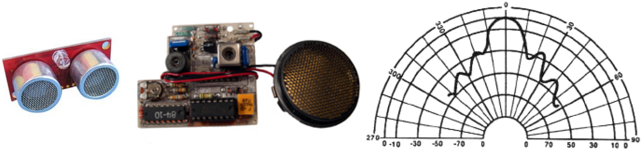




- Small error in heading causes constantly growing lateral position error
- Sensors for heading determination: Compass, gyroscope
- Compass measurement influenced by the environment
- Gyroscopes integrate angular velocities $\Rightarrow$ drift causes significant errors
- Precision x price: airline gyros drift $0.1^\circ/6$ hours,CB IMU300 $30^\circ/1$ hour

Range sensors

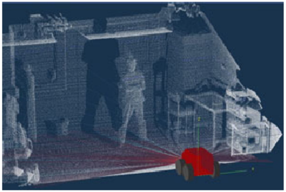
Ultrasonic sensors (sonars)



- Measure depth by emitting an ultrasonic pulse and timing interval until echo returns.
- Fairly accurate depth measurement in one direction but can give ‘noisy’ measurements in the presence of complicated shapes.
- Robots often have a ring of sonar sensors.

Range sensors

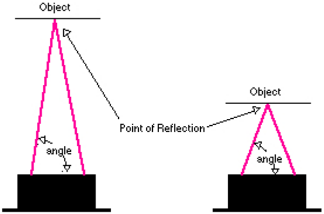
Laser range-finders

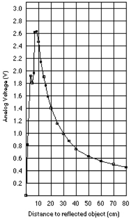


- Very accurate measurement of both depth and direction from time-of-flight measurement of scanning laser beam
- Normally scans in a 2D plane but 3D versions are also available
- Rather bulky (and expensive) for small robots

Range sensors

Infra-red

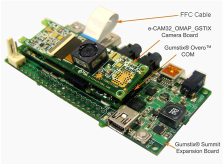




- Low influence on object's color
- No need for external clock/control
- Narrow beam
- Nonlinear Output (Voltage-Distance)
- Low sensitivity at higher distances
- Minimum distance (care at design)
- Slow output change (≈ 40 ms)

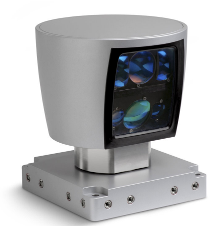
Vision based

camera, 3D



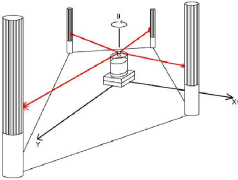
- Vision is powerful sense providing enormous amount of information
- Relatively inexpensive
- Complex sensory processing

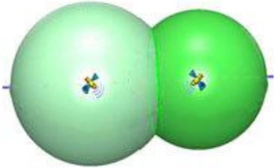
3D sensors



- 360° *HFOV*, 0.09° angular resolution
- 26.8° *VFOV*, 0.4° angular resolution (64 lasers)
- 5-15Hz, 1.3 million point per second
- 50 meter range for pavement (≈ 0.10 reflectivity)
- 120 meter range for cars and foliage (≈ 0.80 reflectivity)

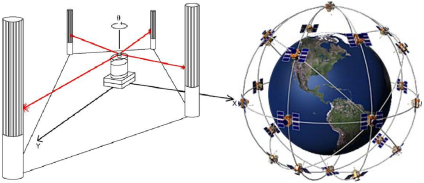
Ground based beacons, GPS

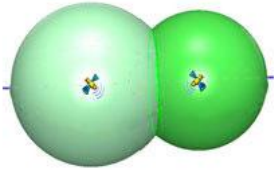




- Active, passive.
- Human use beacon-based navigation.
    - Natural beacons (landmarks) like stars, mountains or the sun
    - Artificial beacons like lighthouses.
- Used often indoors.
- Outdoors GPS.
    - 1 satellite =

Ground based beacons, GPS





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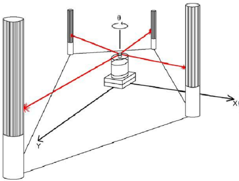
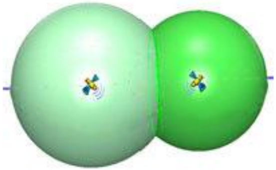
  - 2 satellites =

Ground based beacons, GPS





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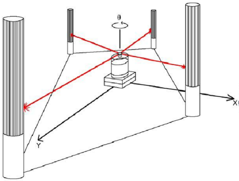
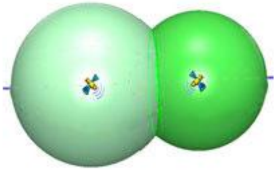
  - 2 satellites =intersection of two spheres
  - 3 satellites =

Ground based beacons, GPS





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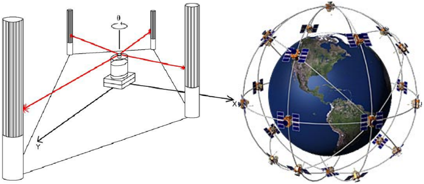
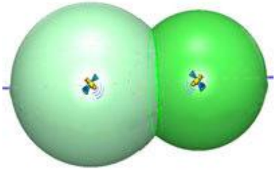
    - Natural beacons (landmarks) like stars, mountains or the sun
    - Artificial beacons like lighthouses.
- Used often indoors.
- Outdoors GPS.
    - 1 satellite = distance
    - 2 satellites =intersection of two spheres
    - 3 satellites = circle
    - $\geq$ 4 satellites =

Ground based beacons, GPS





- Active, passive.
- Human use beacon-based navigation.
  - Natural beacons (landmarks) like stars, mountains or the sun
  - Artificial beacons like lighthouses.
- Used often indoors.
- Outdoors GPS.
  - 1 satellite = distance
  - 2 satellites =intersection of two spheres
  - 3 satellites = circle
  - $\geq$ 4 satellites = unique solution