Overview:

• Mechanisms for acting on the world
• Degrees of freedom and mobility
• Methods of locomotion: Wheels, legs and beyond
• Methods of manipulation: Arms, grippers
• Methods of actuation & choices of hardware
• Control problem: Mapping from signals to actuators to desired world effects
What is a robot?

- A robot is an embodied artificial **agent**. In practice, it is usually an electro-mechanical machine which is guided by computer, and is able to perform tasks with some degree of independence from external guidance.

- Robots tend to do some or all of the following:
  1. **Sense** their environment as well as their own state
  2. Exhibit **intelligence** in behaviour, especially planned behaviour which mimics humans or other animals.
  3. **Act** upon their environment, move around, operate a mechanical limb, sense actively, communicate, ...

adapted from Wikipedia

“Acting and sensing are still the hardest parts. “

(D. Kortenkamp, R. P. Bonasso oder R. Murphy)
Knowledge component

• Computer or brain-like processing device, (symbolic/subsymbolic/hybrid)
• Preprocessing of sensory signals
• Memory: semantic, episodic, declarative, logical
• Adaptation rules for the knowledge components
• Strategy, planning and evaluation
• Working memory
• Actuator control
Replicating fossil paths with toilet roll
T. Prescott & C. Ibbotson (1997)

Control combines thigmotaxis (stay near previous tracks) & phobotaxis (avoid crossing previous tracks)
Components of robots

- Sensory components: Acquisition of information
- Information processing and control
- Actuatory and effectory components: Realization of actions and behaviour

- Plus: Batteries, communication devices, interfaces, central executive, self-evaluation, learning mechanisms, tools for inspection, middleware, ...
Sensor categories

• **Exteroception**: Perception of external stimuli or objects (distance and contact)

• **Proprioception**: Perception of self-movement and internal states

• **Exproprioception**: Perception of relations and changes of relations between the body and the environment (combination of proprioception and exteroception)
Actuatory components

Actuators and effectors can be classified into
('analogous to the sensory part?)

• components relating to the environment
• components relating to the own body
• components relating to perception
• components relating to communication
Effectors and Actuators

Key points:

- Mechanisms for acting on the environment
- ‘Degrees of freedom’
- Methods of locomotion: Wheels, legs etc.
- Methods of manipulation: Arms, grippers, suction cups
- Methods of actuation and transmission
- The control problem: Relations between input signals and actuators and the desired effects
Effector: A device that affects the physical environment

• Choice of effectors sets upper limit on what the robot can do

• Locomotion:
  – Wheels on a mobile robot
  – or legs, wings, fins, claws, suction cups …
  – Whole body movements: Snakes, caterpillars

• Manipulation:
  – Grippers on an assembly robot
  – or welding gun, paint sprayer, …
  – Whole body might be used push objects

• In both cases consider the degrees of freedom in the design

• Further option: Effects by signals such as speakers, light, pen
Degrees of freedom

- General meaning: How many parameters needed to describe a rigid object?
- E.g. for an object in space:
  - Position: \( x, y, z \)
  - Rotation: Roll, pitch, yaw

- Total of 6 degrees of freedom
- How many d.o.f. to specify a vehicle on a flat plane?
Odometry

Odometry: Position measurement by distance travelled
- Know current position \((x, y, \theta)\)
- Know how much wheels rotate
- New position = old position + commanded motion

Note:
- Errors add up \(ightarrow\) good calibration required
- Motors/timing may be inaccurate
  \(\rightarrow\) use shaft encoders
- Wheels slip on surface \(\rightarrow\) use landmarks/beacons
  need some feature tracking
Degrees of freedom

In relation to robots consider:

• How many joints/articulations/moving parts?
• How many individually controllable moving parts?
• How many independent movements with respect to a co-ordinate frame?
• How many parameters to describe the position of the whole robot or its end effector?
• **How many moving parts?**
  • If parts are linked need fewer parameters to specify them.

• **How many individually controllable moving parts?**
  • Need that many parameters to specify robot’s configuration.
  • Often described as ‘controllable degrees of freedom’
  • But note, robot may be *redundant* e.g. two movements may be in the same axis
  • Alternatively called ‘degrees of mobility’
• How many degrees of mobility in a human arm? In a knee joint?
• How many degrees of mobility in the arm of an octopus?

• Redundant manipulator
  Degrees of mobility > degrees of freedom
• Result is that have more than one way to get the end effector to a specific position
• How many independent movements with respect to a co-ordinate frame?
• Controlled degrees of freedom of the robot
• May be less than controllable degrees of freedom
• How many parameters to describe the position of the whole robot or its end effector?
• For fixed robot, d.o.f. of end effector is determined by d.o.f. of robot (max 6)
• Mobile robot on plane can reach position described by 3 d.o.f., but if the robot has fewer d.o.f.
  then it cannot do it directly — it is non-holonomic
Alternative vehicle designs

- ‘Car’- steer and drive
- Two drive wheels and castor 2DoF
  - Three wheels that both steer and drive
- Omni-wheels may be easier for path planning, but is mechanically more complex
Locomotion on uneven terrain

- Use the world (ramps etc.)
- Larger wheels
- Suspension
- Tracks
Alternative is to use legs

Note: Wheels and variants are faster, for less energy, and are usually simpler to control
Legged locomotion

Strategies:
Statically stable control
  e.g. ‘Ambler’
Whittaker, CMU

Keep three legs on ground at all times
Legged locomotion

Strategies:
Dynamic balance e.g. Raibert’s hopping robots
Keep motion of center of gravity within control range
Legged locomotion

 Strategies:

 ‘Zero moment point’ control, e.g. ASIMO

 Keep point where static moment is zero within foot contact hull
Legged locomotion

Strategies:

Limit cycle in dynamic phase space e.g. ‘Tekken’ (H. Kimura)

Cycle in joint phase space + forces that return to cycle
Legged locomotion

Strategy:
Exploit natural dynamics with only gravity as the actuator

E.g. passive dynamics walkers

hybrid active/passive walkers

P Manoonpong, T Geng, B Porr, F Wörgötter (2005) RunBot
BigDog

Sensors for joint position and ground contact, laser gyroscope and a stereo vision system.

Boston Dynamics with Foster-Miller, NASA Jet Propulsion Laboratory, Harvard University Concord Field Station (2005)
E.g. Robot III vs. Whegs

Roger Quinn et al. – biorobots.cwru.edu

Realistic cockroach mechanics but difficult to control (Robot III), vs. pragmatic (cricket?) kinematics, easily controllable

Exploit dynamics of mechanical system, e.g. RHex

Springiness restores object to desired state
Other forms of locomotion?

Swimming: e.g. robopike project at MIT

Flight: e.g. Micromechanical Flying Insect project at Berkeley
Other forms of locomotion?

Gavin Miller: snake robots

George M. Whitesides: Soft robots
Robot arms

• Typically constructed with rigid links between movable one d.o.f. joints
• Joints typically
  – *rotary* (revolute) or prismatic (linear)
Robot arm end effectors

- Simple push or sweep
- Gripper – different shape, size or strength
- Vacuum cup, scoop, hook, magnetic
- Tools for specific purposes (drills, welding torch, spray head, scalpel,…)
- Hand for variety of purposes
Actuation

What produces the forces to move the effectors?

Electrical:
- DC motors (speed proportional to voltage – voltage varied by pulse width modulation)
- Stepper motors (fixed move per pulse)

Pressurised -
- Liquid: Hydraulics
- Air: Pneumatics, air muscles

Connected via transmission: system gears, brakes, valves, locks, springs…
Non-conventional actuators

Rotary electric motors  Electromechanical
Hydraulics  Pistons
Pneumatics  Electrochemical
Piezoelectric  Magnetostrictive
Bimetallic  Rheological
Shape memory alloy ...
Issues in choosing actuators

• Load (e.g. torque to overcome own inertia)
• Speed (fast enough but not too fast)
• Accuracy (will it move to where you want?)
• Resolution (can you specify exactly where?)
• Repeatability (will it do this every time?)
• Reliability (mean time between failures)
• Power consumption (how to feed it)
• Energy supply & its weight
• Usually many possible trade-offs between physical design and ability to control
The control problem

- For given motor commands, what is the outcome? \(= \text{Forward model}\)
- For a desired outcome, what are the motor commands? \(= \text{Inverse model}\)
- From observing the outcome, how should we adjust the motor commands to achieve a goal? \(= \text{Feedback control}\)
The control problem

Want to move robot hand through set of positions in task space – $X(t)$

$X(t)$ depends on joint angles in the arm $A(t)$

$A(t)$ depends on the coupling forces $C(t)$ delivered by the transmission from the motor torques $T(t)$

$T(t)$ produced by the input voltages $V(t)$

$V(t) \leftrightarrow T(t) \leftrightarrow C(t) \leftrightarrow A(t) \leftrightarrow X(t)$
The control problem

\[ V(t) \leftarrow T(t) \leftarrow C(t) \leftarrow A(t) \leftarrow X(t) \]

- Depends on geometry & kinematics: can mathematically describe the relationship between motions of motors and end effector as transformation of co-ordinates
- as well as on dynamics: motion depends on forces, such as inertia, friction, etc
- **Forward kinematics** is hard but usually possible
- **Forward dynamics** is very hard and at best will be approximate
- But what we actually need is **backwards kinematics and dynamics**
Summary

• Various energy sources: electrical, hydraulic, air, muscles, …
• A variety of effectors: wheels, legs, tracks, fingers, tools, …
• Degrees of freedom and joints
• Calculating control may be hard: Choose either a sufficiently simple environment or adapt to the environment by learning
Bio-inspired Robotics


Simulation of Braitenberg Vehicles: http://people.cs.uchicago.edu/~wiseman/vehicles/