COMP20170
Introduction to Robotics

Dr Eleni Mangina
Room B2.05
School of Computer Science & Informatics
Ext. 2858
eleni.mangina@ucd.ie

Lecture Plan

- Most weeks will consist of 1 hour lecture (Thursday 1-2pm) and a compulsory 2 hour lab (Friday 4-6pm). Please use csimoodle.ucd.ie week by week for details.

Robotics

Robotics integrates science and engineering, and overlaps with many disciplines:

- Artificial Intelligence
- Computer Vision / Perception
- Machine Learning / Estimation / Inference
- Cognitive Science
- Electronic / Mechanical Engineering

What is a Robot?

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.
- *Pixels to torques...*

What is a Robot?

- 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.
- What about a modern car? Or smartphone?

Robot Arms..

- The most widely-used robots today are industrial robot ‘arms’, mounted on fixed bases and used for instance in manufacturing.
- The task of a robot arm is to position an end-effector through which it interacts with its environment.
- Most operate in highly controlled environments.

More Robots..

- They need perception which gives them a suitable level of understanding of their complex and changing surroundings.

Robot for home

There is a new wave of advanced mobile robots now aiming at much more flexible robots which can interact with the world in human-like ways. This is the current goal of significant research teams; e.g. Willow Garage and Evolution Robotics in the USA.

See the video at `http://personalrobotics.stanford.edu/` from Stanford's Personal Robotics Program.

Real World Manipulation

- Laundry-folding robot from UC Berkeley / Willow Garage
  http://www.youtube.com/watch?v=Thpjk69h9P8

Mobile robots

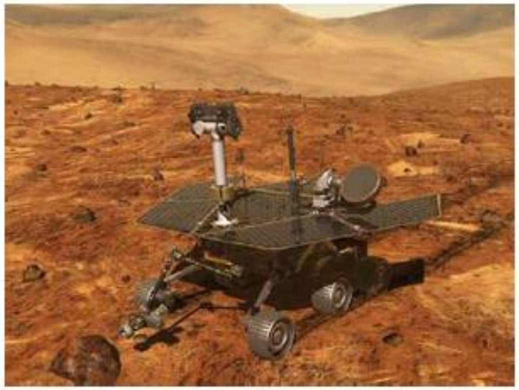
- A mobile robot needs actuation for locomotion and sensors for guidance.
- Ideally untethered and self-contained: power source, sensing, processing on-board (return to charging station? on-board computing? outside-in sensing?)
- Required competences include:
  - Obstacle avoidance
  - Localisation
  - Mapping
  - Path planning

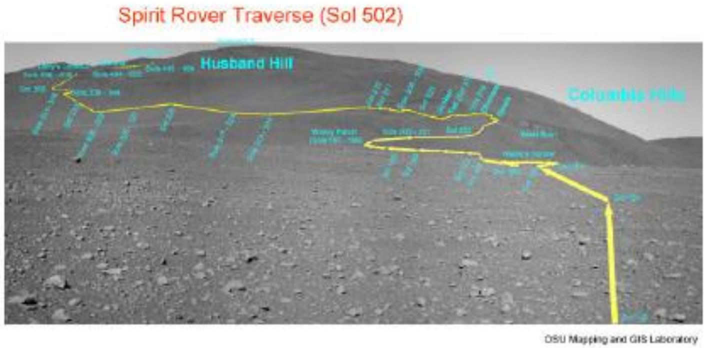
Robot Applications

- 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, laundry, clearing the table. .)
  - Medical (helping the elderly, hospital delivery, surgical robots).
  - Transport (Autonomous cars).
  - Entertainment (Sony AIBO, QRIO, **Lego Mindstorms**, Robocup competition, many others).

Mobile Robots

Mars Rovers Spirit and Opportunity (NASA)

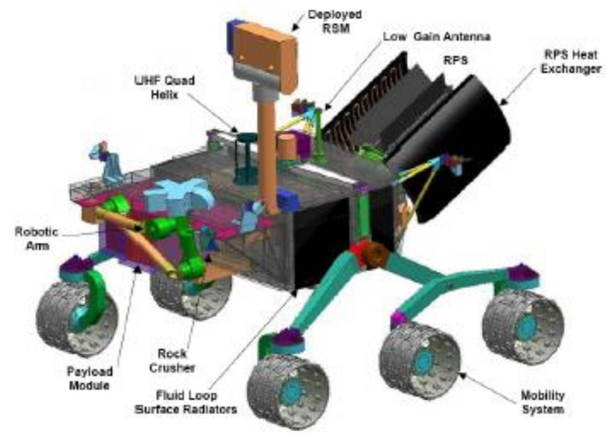




- Both had successful missions on Mars in starting in late 2004. Spirit went 'silent' in March 2010; Opportunity is still operational and has to date covered more than 34km.
- 1.6m long; 180kg. 9 cameras (Hazcams, Navcams, Pancams, microscopic).
- Remote human planning combined with local autonomy.
- Increased autonomy as mission has progressed.

Mobile Robots

Mars Science Laboratory: Curiosity Rover



- Landed on Mars August 2012.
- Five times larger than Spirit/Opportunity; designed to explore at least 1 Martian year (689 Earth days), travelling 5–20km. Maximum speed 90m/hour.
- Radiation-hardened computer and backup. 10 cameras (6 for navigation, 4 for science).
- Many remote sensing and scientific instruments for studying geology, atmosphere, biosignatures.

Mobile Robots

DARPA Grand Challenge 2005 winner "Stanley" (Stanford University, USA).

- Completed 175 mile 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

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.
- Current state of the art: Google car
  `http://www.youtube.com/watch?v=bp9KBrH8H04`

Animal-like Waling Robots

Animal-like Walking Robots

- BigDog (Boston Dynamics; recently acquired by Google)
  `http://www.youtube.com/watch?v=cNZPRsrwumQ`
- LittleDog (USC/Boston Dynamics)
  `http://www.youtube.com/watch?v=nUQsRPJ1dYw`
- WildCat (Boston Dynamics)
  `http://www.youtube.com/watch?v=wE3fmFTtP9g`

Humanoids

Humanoid HRP-2 (AIST, Japan)

- Several high-performance research humanoids now presented (since pioneering work by Honda in 1990s).
- Impressive movement but so far limited sensing and autonomy.

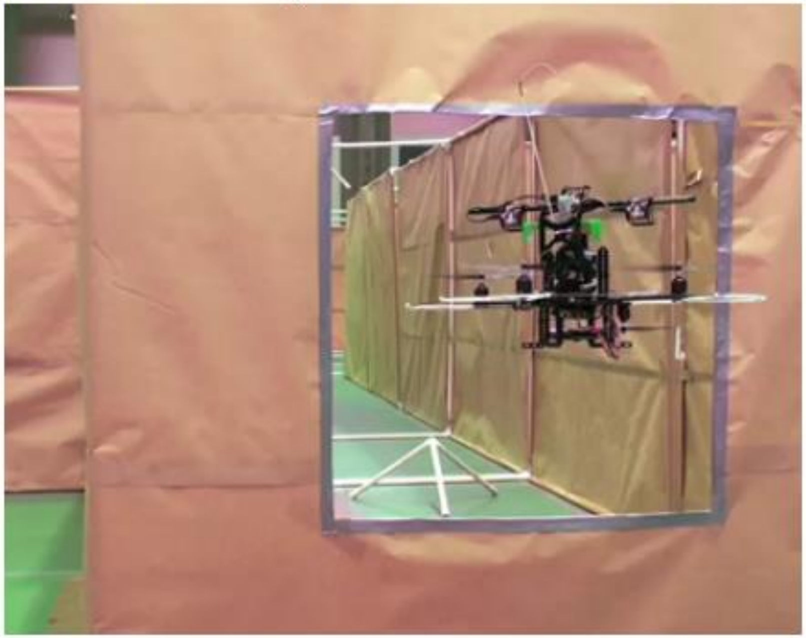
Humanoids

New Generation Humanoid Robotics (Darpa Robotics Challenge 2013/2014)

- Schaft, another company just acquired by Google!
- At this stage still quite specifically programmed for these tasks but watch for big improvements soon. `http://www.youtube.com/watch?v=diaZFIUBMBQ`

UAVs

Autonomous Aerial Navigation (MIT Robust Robotics Group)



- Quadcopters; highly manoeuvrable and relatively easy to control.
- Inertial, laser, vision sensors; with or without GPS.
- Many applications (inspection, search and rescue, . . .)
- `http://www.youtube.com/watch?v=5qQJwLJ857s`

Robot Vacuum Cleaner

iRobot 'Roomba' Robot Vacuum Cleaner, first launched in 2002

- 'Random bounce' movement style with short-range IR sensing.
- Over 6 million units sold!
- Second generation and competing products are now aiming at precise navigation.

Locomotion

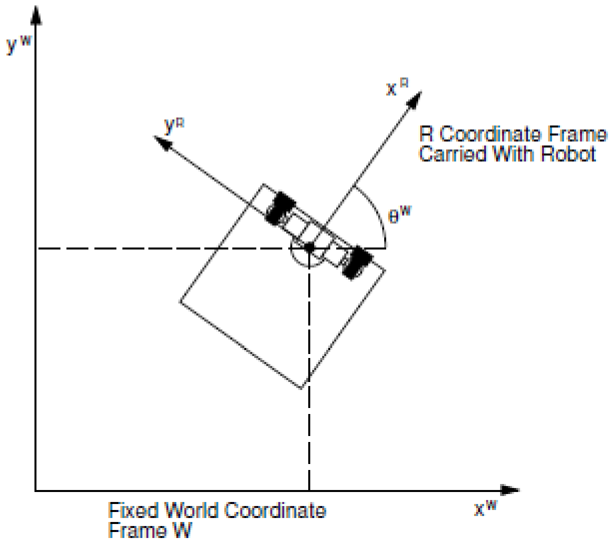
- Wheels are most common, in various configurations.
- Legs increase mobility, but with much extra complication.
- Robot size affects power requirements/efficiency, actuator specifications.

Autonomous Underwater Vehicle

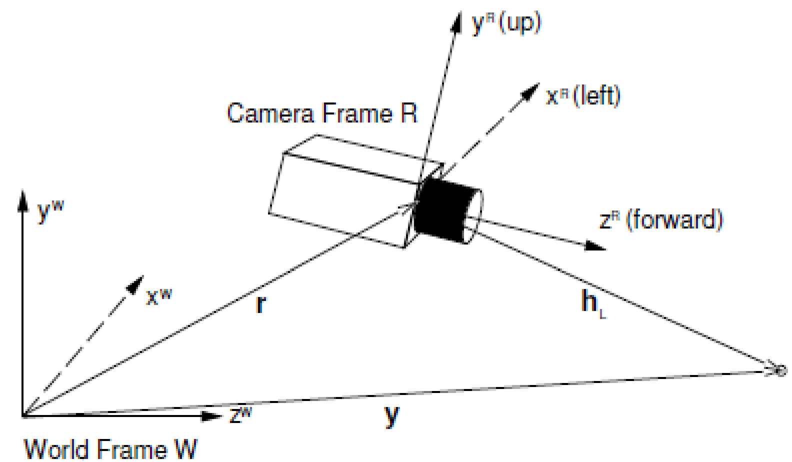
Unmanned Aerial Vehicle

Motion and Coordinate Frames

- 'Pose' means position and orientation taken together.



2D Pose



3D Pose

- More generally, we will talk about about a robot's *state*, which is a set of parameters describing all aspects of interest.

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 magntetic compass would normally be considered proprioceptive sensing).

- Most mobile robots have various sensors, each specialised in certain tasks. Combining information from all of these is often called ‘sensor fusion’.

Proprioceptive sensing

Sensors which measure a robot's internal state:

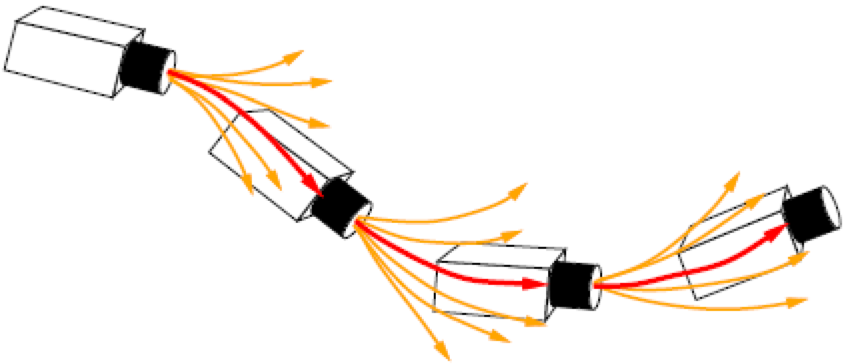
- Wheel odometry (encoders, or just checking voltage level and time).
- Tilt sensors (measure orientation relative to gravity).
- Gyros (measure angular velocity).
- Compass.
- Internal force sensors (for balance).

Proprioceptive sensors give a *local* measurement of motion

- e.g. Self-balancing Lego Robots built by DoC students in 2008: `http://www.youtube.com/watch?v=fQQctJz7ap4`

Uncertainty in Motion

- If a robot has proprioceptive sensing such as odometry to calculate its position, why does it also need external sensing and mapping?
- Because all sensors have uncertainty, and when local motion estimates are integrated drift occurs.



- The way to resolve drift is to build a *map* of the static world.

Outward looking sensors

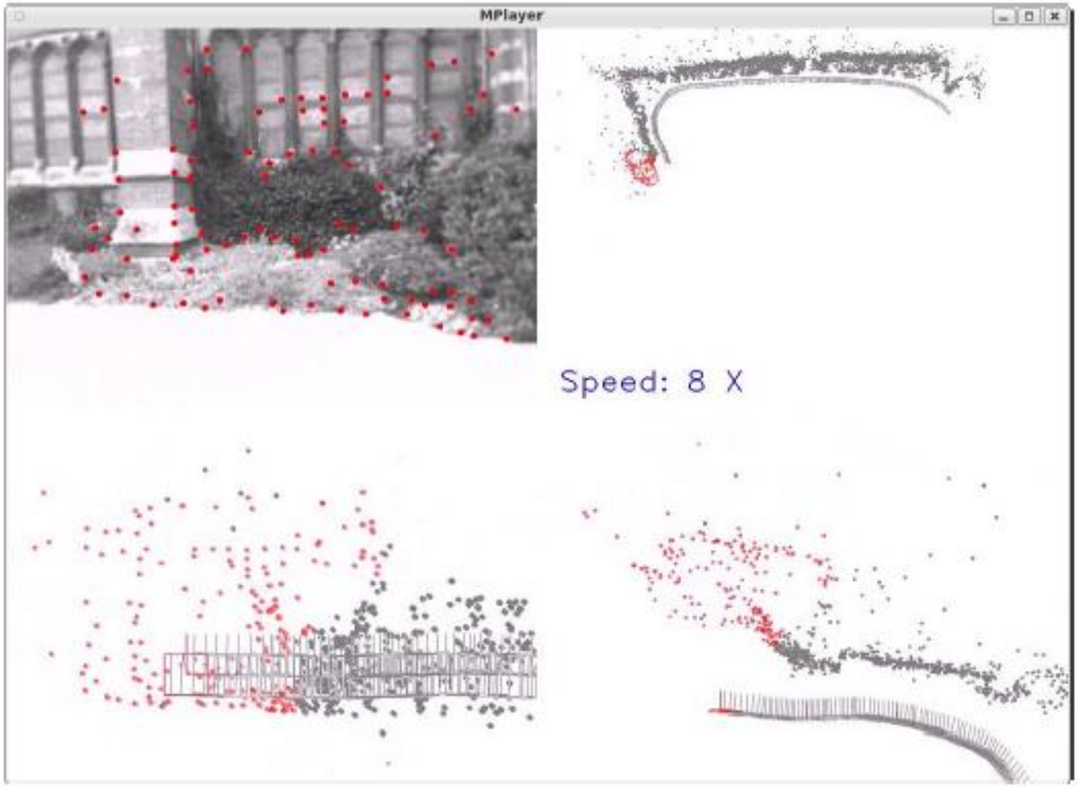
- Sense at a distance (using sound waves, infra-red laser, visible light).
- Active (sonar, laser range-finder, structured light system) — send and receive; or passive (camera, microphone) which just receive ambient signals.
- Complex data requires significant processing to extract useful information.

SLAM with Laser Range-Finder

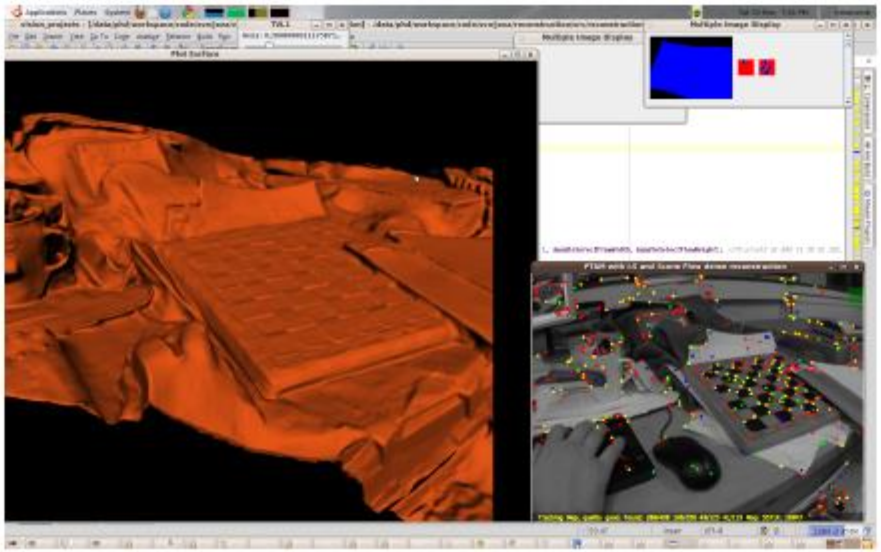
Paul Newman and David Cole, University of Oxford, 2006.

Large Scale Monocular SLAM using Optimisation

Scale Drift-Aware Large Scale Monocular SLAM (Strasdat, Montiel, Davison, Robotics: Science and Systems 2010).



Real-Time Dense SLAM



Live Dense Reconstruction with a Single Camera (2010); KinectFusion (2011)

- During live camera tracking, perform dense per-pixel surface reconstruction.
- Relies heavily on GPU processing for dense image matching.
- Runs live on current desktop hardware.

Computer Processing

Level of autonomy:

1. Teleoperation (Remotely-Operated Vehicle ROV, e.g. Robot Wars, mine clearing).
2. Semi-autonomous (e.g. Mars rovers, humanoids).
3. Fully autonomous (Roomba, Grand Challenge vehicles).

Computing requirements:

- Embedded processing: specialised or general PC architecture? GPU, FPGA, etc.
- Computer vision in particular can be very computationally expensive.
- A set of requirements for robot processing might be: *efficient, automatic, robust*.

Robot Algorithms

- In-depth planning involving logic-based reasoning.
- Probabilistic combination of prior knowledge (heuristics, maps, object models) with sensor data to form a coherent/metric world model; planning with uncertainty.
- Simple sensing/action loops involving feedback (e.g. subsumption).
- *Learning* at local and high levels.

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In groups you will use the Lego Mindstorms EV3 kits to build mobile robots and implement techniques such as:

- Wheeled configurations and uncertainty in movement.
- Using simple sensors to implement reactive behaviours.
- Investigating the characteristics of advanced sensors like sonar.
- Implementing a probabilistic localisation filter…?

COMP20170: Coursework and Assessment

- The coursework component is based on accumulative assessment of achievement in the practical sessions and one submission of a written reports. From next onwards you will be set a practical task each week, most of which (and each practical sheet will very clearly say which) will be ASSESSED.
- At the start of the practical I will ask you all to organise yourself into groups of 3 or 4 depending on total numbers; I need people to commit to the course at this point.
- Each assessed practical exercise will have a number of well-defined objectives with a defined number of marks for each. Most of these objectives involve practical demonstration of your robots or oral explanation of results.
- We will mark these exercises by visiting all groups at the start of the next week's practical session, where each group must demonstrate their robot and discuss with me or a lab assistant.
- We will check attendance in each group at the assessments and will ask questions to make sure each group member has been involved.

COMP20170: Coursework and Assessment

- The total marks from the assessed practical will form your overall coursework mark for COMP20170.
- One written essay will be set.
- All members of a group will receive the same mark by default (unless I have a strong reason to believe that certain members are not doing their share of work).
- No Final Exam Paper

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- On completion of this module you should be able to understand current and future trends in Robotics and how they operate.
- You will be able to write and debug simple programs that move a robot around an environment while avoiding objects that block its path.
- You will learn ways to make a robot follow a line on the floor; follow a wall or stay away from a drop off such as stairway
- You will have an up-to-date knowledge of important robotics and simulations systems as well as critically assess theory and applications in the area.

Journal

- Weekly logs have to be kept from each group
- Continuous assessment will be based on the activity logs of the group and
- The outcome from each competition
- We will follow the CMU curriculum for the lab: http://www.education.rec.ri.cmu.edu/previews/ev3_products/robotc_ev3_curriculum/

Essay Assignment
Deadline: Week 11 (20%)

- Select a Robot of your choice that has been implemented the last 5 years and within an essay of 3000 words:
  - Outline the functionality of the Robot
  - Describe the software and hardware of the Robot
  - Provide the technology that has been utilised
  - Identify the Artificial Intelligence techniques that have been implemented
  - Provide details of its application area and criticise its usage
  - Compare the Robot’s technology with similar other solutions if they exist
  - Illustrate the market need for this Robot
  - Summarise and predict its future usage and potential