Robotics

Lecture 1: Introduction to Robotics

See course website
http://www.doc.ic.ac.uk/~ajd/Robotics/ for up to date information.

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Lecture Plan

Most weeks will consist of a **1 hour lecture (Tuesday 9am, 311)** and a **compulsory 3 hour practical session (Tuesday 10-11am, 202 and Friday 2-4pm, 202)**. There may some variations from week to week which will be fully detailed on the course website and announced in lectures.

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Robotics: An Inter-Disciplinary Field

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

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

In fact the differentiation between these fields is sometimes artificial. I recently heard someone (Greg Dudek) wonder whether robotics is the new physics? An umbrella science of the synthetic and interactive...

- In this course the emphasis will be largely pragmatic.

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? Are they becoming robots?

The Classical Robot Industry: 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.

Robots for the Wider World

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

A Fully Autonomous Robot for the 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. Over recent years this has again become the current goal of significant research teams; e.g. Willow Garage in the USA.

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

Advanced ‘Real-World’ Manipulation

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

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 (return to charging station? off-board computing? outside-in sensing?)
- Required competences include:
  - Obstacle avoidance
  - Localisation
  - Mapping
  - Path planning
- As well as whatever specialised task the robot is actually trying to achieve!

Mobile Robotics Applications

Field Robotics

- Exploration (planetary, undersea, polar).
- Search and rescue (earthquake rescue; demining).
- Mining and heavy transport; container handling.
- Military (unmanned aircraft, land-based pack-bots, insect robots).

Service Robotics

- Domestic (Vacuum cleaning, lawnmowing, laundry, more general clearing and cleaning. . . ?).
- Medical (surgical robots, remote doctor, hospital delivery, helping the elderly).
- Transport (Autonomous cars, parcel delivery).
- Entertainment (Sony AIBO, Lego Mindstorms, Robocup competition, Parrot AR Drone, many others).

Autonomy and Processing for Mobile Robotics

Level of autonomy:

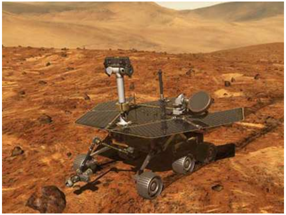
1. Teleoperation (Remotely-Operated Vehicle ROV, e.g. Robot Wars, mine clearing).
2. Semi-autonomous (e.g. Mars rovers, humanoids).
3. Fully autonomous (Roomba, Grand Challenge vehicles).

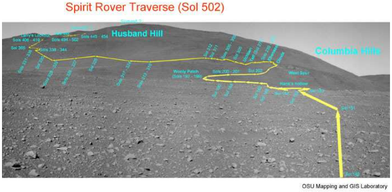
Computing requirements:

- Embedded processing: specialised or general PC architecture? GPU, FPGA, etc.
- Computer vision in particular can be very computationally expensive.

Mobile Robots: State of the Art

Mars Rovers Spirit and Opportunity (NASA)

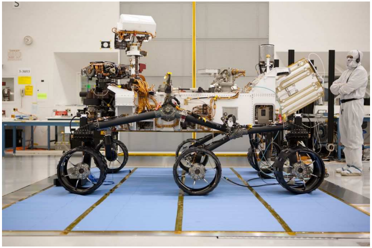


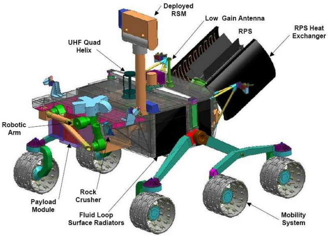


- Both had successful missions on Mars in starting in late 2004. Spirit went ‘silent’ in March 2010; Opportunity is still operational and has to date covered more than 40km.
- 1.6m long; 180kg. 9 cameras (Hazcams, Navcams, Pancams, microscopic).
- Remote human planning combined with local autonomy.
- Increased autonomy as mission progressed.

Mobile Robots: State of the Art

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: State of the Art

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. `https://www.youtube.com/watch?v=FLi_IQgCxbo`

Mobile Robots: State of the Art

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

- 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`
- Most car companies and other new ones now have major autonomous car projects.

Mobile Robots: State of the Art

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`

(These don't currently have on-board visual sensing.)

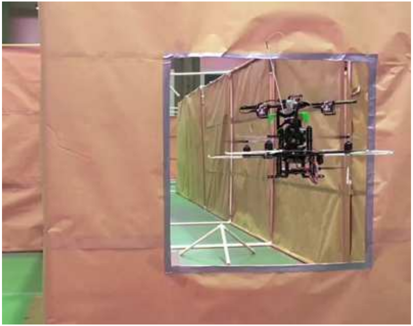
Mobile Robots: State of the Art

New Generation Humanoid Robotics (Darpa Robotics Challenge 2013–2015)

- Schaft, another company recently 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

Mobile Robots: State of the Art

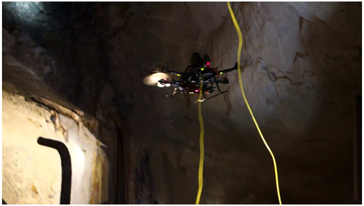
Autonomous Aerial Navigation (MIT Robust Robotics Group)

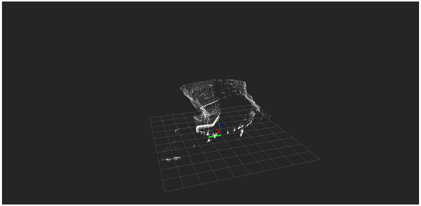


- Quadcopters; highly manoeuvrable and relatively easy to control.
- Inertial, laser, vision sensors; with or without GPS.
- Many applications (inspection, search and rescue, . . .)
- `http://www.youtube.com/watch?v=5qQJwLJ857s`

Mobile Robots: State of the Art

Multicopter Visual-Inertial On-Board Estimation
(Autonomous Systems Lab, ETH Zurich)





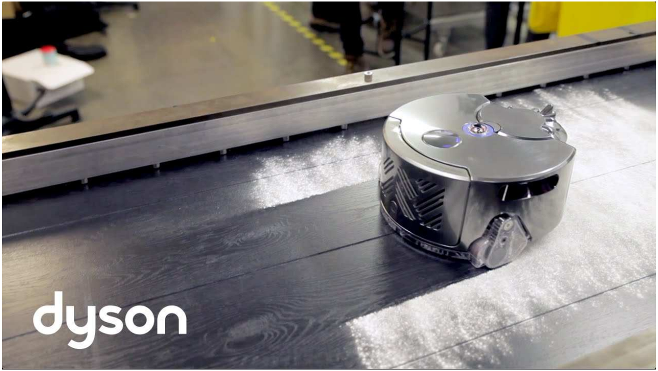
- Application: automatic mapping of a poorly accessible gold mine.
- Using camera and inertial sensors only (accelerations and angular rates) for localisation and building a map of sparse landmarks.
- Laser scans provide a rough live reconstruction

Mobile Robots: State of the Art

iRobot ‘Roomba’ Robot Vacuum Cleaner, first launched in 2002

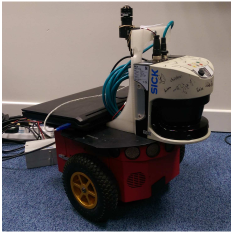
- ‘Random bounce’ movement style with short-range IR sensing.
- Over 10 million units sold!
- Second generation and competing products are now aiming at precise navigation.

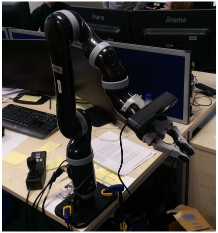
Dyson 360 Eye



- On sale in Japan in 2015; around the world in 2016.
- Uses omnidirectional vision to build a map of its environment automatically (SLAM). This permits accurate, repeatable localisation, and therefore precise coverage and cleaning.

The Dyson Robotics Laboratory at Imperial College





- Founded in 2014, funded by Dyson and led by Andrew Davison and Stefan Leutenegger, this new lab researches the vision and robotics technology that we hope will open up new categories in robotic products for the home. `http://www3.imperial.ac.uk/dyson-robotics-lab`.
- Part of a thriving robotics research community across Imperial College: `http://www3.imperial.ac.uk/robot`.

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Robotics: Requirements

1. Essential geometry (vectors, rotations, trigonometry).
2. Essential probability theory.
3. Programming: you will write a lot of code in Python.
4. Willingness to work with robot kit hardware, which is not always. reliable.

Robotics: Learning Outcomes

By the end of the course you should understand:

1. The defining properties of a robot: sensing and action, linked by processing.
2. An overview of the practical issues of modern-day mobile robotics.
3. Robot locomotion methods, particularly wheel configurations and uncertainty in motion.
4. Tuning a basic motor controller; 2D path planning.
5. The use of simple sensors in reactive, behavioural programming.
6. The key concepts of advanced outward looking sensors such as sonar and vision.
7. The essentials of probabilistic techniques in robotics; probabilistic localisation and SLAM.
8. Techniques for robot programming in Python.

Locomotion

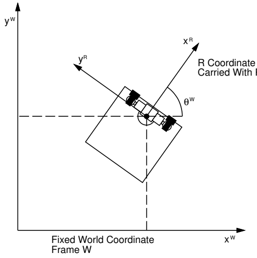


- Wheels are most common, in various configurations.
- Legs increase mobility, but with much extra complication.
- Underwater or flying robots have different locomotion systems which obviously enable 3D locomotion.

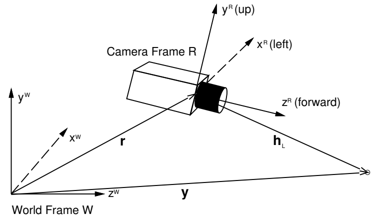
Moving robots usually have some form of **odometry**: the ability to estimate its movements from internal measurements of its actuators. For wheeled robots, we measure and integrate the velocity commands sent to each wheel. e.g.: Bigtrak!
`https://www.youtube.com/watch?v=MDGIOv-2uf0`.

Motion and Coordinate Frames

- 'Pose' means position and orientation taken together.



2D Pose

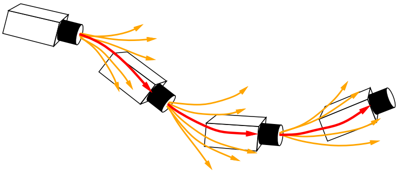


3D Pose

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

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.



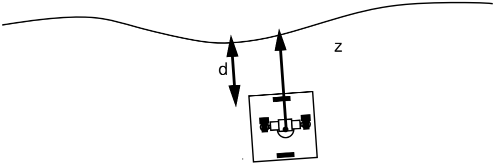
- The way to resolve drift is to refer to a *map* of the static world. To make contact with and make measurements of elements of this map we need outward-looking sensors.

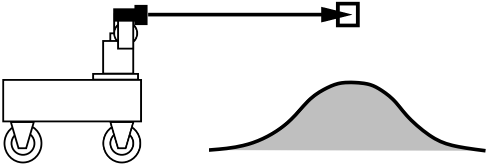
Outward-Looking Sensors



- 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.
- Simple sensors often directly provide measurements which are directly useful for navigation, though generally this is quite sparse. Camera images have much more detailed information but require significant processing to extract useful measurements.
- Localisation against a map using sonar: `http://vimeo.com/10258746`.

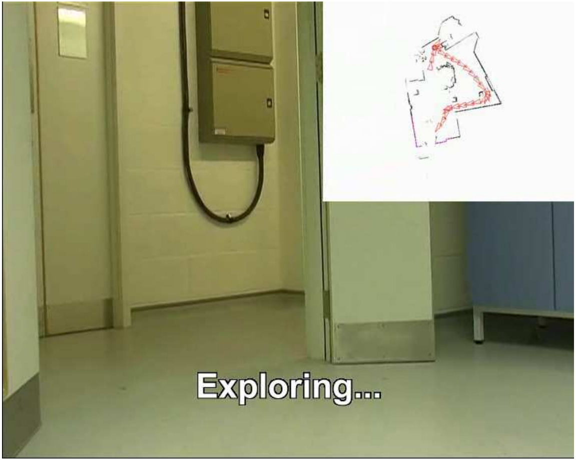
Reactive Behaviours vs. Probabilistic Estimation





- Either use outward-looking sensor measurements as they arrive a reactive control loops (like wall following), or combine many measurements into a global estimate of scene and motion using probability theory.

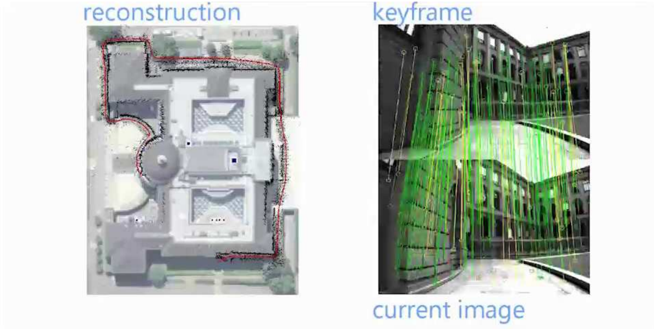
SLAM: Building a Map On the Fly



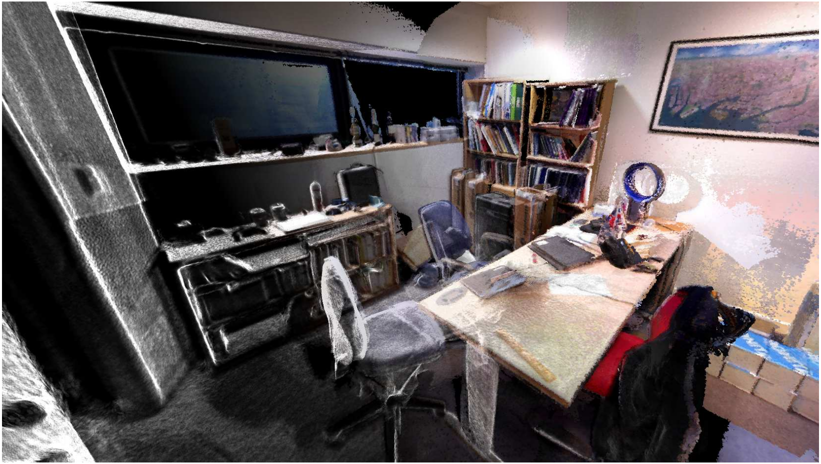
- 2D SLAM with a laser range-finder; Paul Newman and David Cole, University of Oxford, 2006.

Large Scale Visual-Inertial SLAM Using Optimisation

Keyframe-Based Visual-Inertial Odometry (Leutenegger, *et.al*, The International Journal of Robotics Research, 2014).

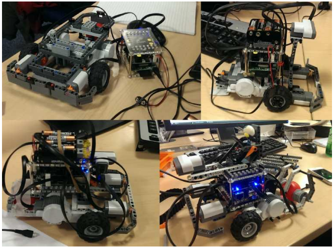


ElasticFusion: Reliable Room-Scale Dense Mapping



- Maps a scene with millions of surfels and corrects loop closures.
- Relies on a depth camera and GPU processing.

Robotics: A Practical Course



Next week, in groups you will be given a robotics kit which you will keep throughout term to work on practical exercises every week. We will use these 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 and precise waypoint navigation.
- Place recognition and free space mapping.

Raspberry Pi Robotics

As we started in 2014, this year we will base the practical work around the Raspberry Pi single board computer, using 'BrickPi' boards to interface with Lego motors and sensors (rather than using the Lego LXT Brick). This has many advantages; including:

- Flexible programming in Python/Linux and all sorts of open source tools are available.
- Decent processing power and much more flexibility in programming.
- Wi-Fi connection to a PC.
- And new for 2015: better motor and sensor control via our new custom controller, and rechargeable battery packs.

Robotics: Coursework and Assessment

The coursework component is based on cumulative assessment of achievement in the practical sessions and there will be no submission of 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*.

- Next week, at the end of the lecture we will ask you all to organise yourself into practical groups of 4–5 members depending on final numbers; we need people to commit to the course at this point.
- Each assessed practical exercise will have a number of well-defined objectives with a specified 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.

Robotics: Coursework and Assessment

- The total marks from the assessed practicals will form your overall coursework mark for Robotics.
- No extra written coursework will be set.
- All members of a group will receive the same mark by default (unless we have a strong reason to believe that certain members are not doing their share of work).
- Coursework marks in Robotics are worth the same as in most courses — i.e. only around 15% of the total marks available for the whole course. And... **it is a lot of work**. But this is for a good reason. The exam will be designed to tie in closely with the coursework, and those members of groups that have made a good effort during the term have historically done very well on the exam.
- Previous years' exam papers are a good starting point for seeing what the style of questions will be, but every year the exam will change to reflect the current lecture and practical content of the course.

Robotics: Competition

On the final day of the course (11th March), we will have a competition between the groups, testing the performance of the robots developed for the final practical exercise. See the course website for pictures and videos from previous years' competitions . . . but this year's challenge will be different again!

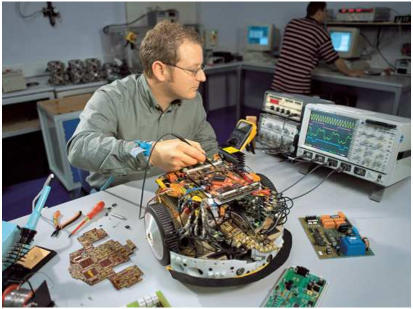
See videos at
`http://www.doc.ic.ac.uk/~ajd/Robotics/index.html`.

Extra Information

- Robotics course web page (will carry course timetable, notes, practical sheets, extra handouts and other information): `http://www.doc.ic.ac.uk/~ajd/Robotics/index.html`
- You should not need to buy any books, but if you want some more background we can recommend the following:
  - 'Probabilistic Robotics', Sebastian Thrun, Wolfram Burgard and Dieter Fox
- Also see relevant free online courses, e.g. from Udacity.

Week 1 Tutorial: Robot Floor Cleaner

- Dyson DC06: almost released in 2004 but never went on sale.



- In many ways floor cleaning presents an unusual mobile robot navigation problem; rather than just get from A to B it has to visit *everywhere* in a domain.

Some Robot Floor Cleaners on the Market


Roomba

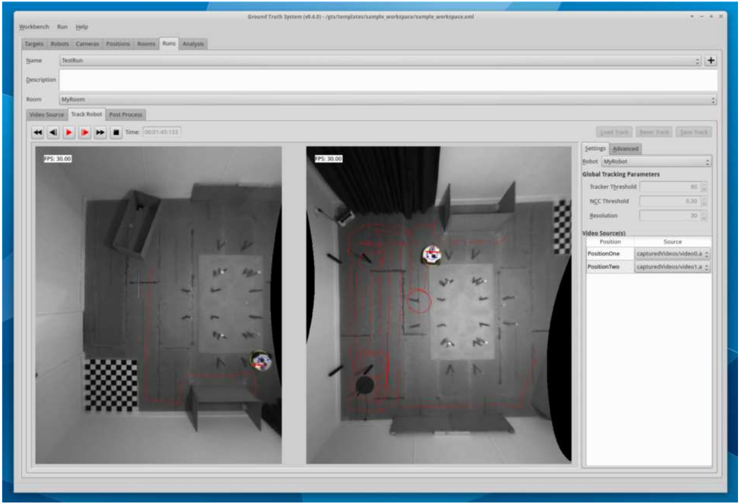

Navibot


Mint


Neato

Roomba (iRobot), floor coverage
`http://www.youtube.com/watch?v=0MUhSBeIm40`
Mint Floor Cleaner (Evolution Robotics)
`http://www.youtube.com/watch?v=6Cf55mIaNGw`

Evaluating Robot Floor Cleaners



- Dyson 'GTS' open source ground truth evaluation system based on ceiling-mounted cameras.