Robotics

Lecture 1: Introduction to Robotics

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

Andrew Davison
Department of Computing
Imperial College London

Lecture Plan

The regular schedule will be a **1 hour live lecture (Tuesday 4pm)** and a **compulsory 3 hour practical session (Tuesday 5pm, and Friday 4–6pm)**. There may some variations from week to week which will be fully detailed on the course website and announced in lectures, email, EdStem.

This week only there will be a two hour lecture today (Tuesday), and a two hour introductory practical session on Friday. From next week we will start the regular schedule.

1. Introduction to Mobile Robotics and the Course
2. Robot Motion
3. Sensors
4. Probabilistic Robotics
5. Monte Carlo Localisation
6. Advanced Sensing
7. Simultaneous Localisation and Mapping

Course Organisation

- All instructions, the schedule and materials are on the course website at `http://www.doc.ic.ac.uk/~ajd/Robotics/`.
- All lectures and practical sessions will be **live** on Microsoft Teams and/or available face-to-face with the schedule to be confirmed later.
- Live lectures will be recorded and made available soon afterwards on PANOPTO.
- Practical exercises will be set every week. You will work in fixed groups of 2–4 students using the simulator software CoppeliaSim.
- Some practicals will be assessed via demonstration, and this forms the only coursework element of Robotics.
- The exam at the end of term will test everything in the course, but will be especially closely tied to the practical exercises.
- General support on outside of live hours will be given on EdStem.
- We will have a competition at the end of term! This year this will be just for fun, learning and glory; not assessed as part of coursework.

Robotics: An Inter-Disciplinary Field

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

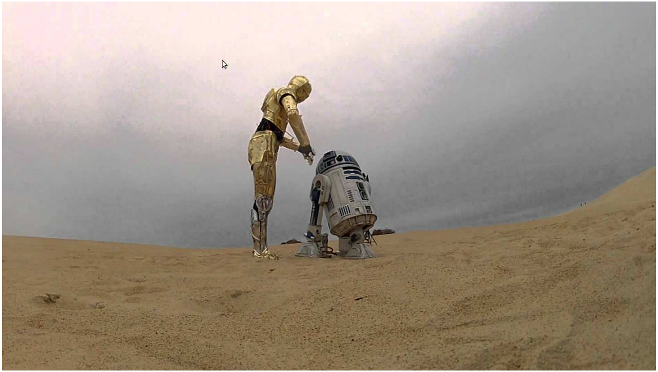
- Artificial Intelligence
- Computer Vision / Perception
- Machine Learning / Estimation / Inference
- Neuroscience
- Electronic / Mechanical Engineering

In fact the differentiation between these fields is sometimes artificial. I recently heard someone (Greg Dudek) wonder whether robotics is the new physics? A major new 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 would call it an appliance instead, 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 and successfully used robots up until now are industrial robot ‘arms’, mounted on fixed bases and used for instance in manufacturing.
- Most operate in highly controlled environments, and carry out repetitive movements.

Robots for the Wider World

- Experimental mobile robots are now being tested in a wide range of challenging application scenarios.

- 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 just as much challenge in developing generally capable robots for the home as there is in those outdoor environments.
- 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.

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

Our Focus: Mobile Robots

- What are the general principles of how robots move? Why and how can they use sensors to understand their environments sufficiently to navigate usefully and safely?
- Required competences include:
    - Movement control
    - Obstacle avoidance
    - Localisation
    - Mapping
    - Path planning
- ... as well as whatever specialised task the robot is actually trying to achieve!
- Real world robots must deal with the noisy nature of real sensors and actuators, and that is what leads us down the path to probabilistic methods.

Mobile Robotics Applications

Field Robotics

- Exploration (planetary, undersea, polar).
- Inpection (factories, bridges, etc.)
- 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 (remote doctor, hospital delivery, helping the elderly).
- Transport (Autonomous cars, parcel delivery).
- Entertainment (Robot pets/companions, robot building kits, robot competitions, Personal drones, many others).

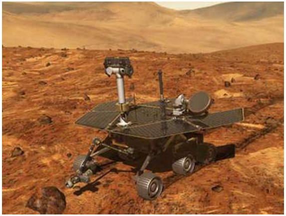
Autonomy and Processing for Mobile Robotics

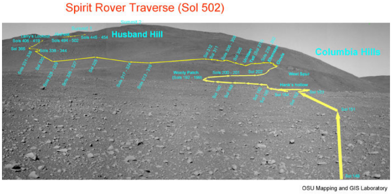
Mobile robots will ideally be untethered and self-contained, with power source, sensing and processing on-board, but other levels of autonomy are possible.
Level of autonomy:

1. Teleoperation (Remotely-Operated Vehicle ROV, e.g. Robot Wars, mine clearing, surgical robots, some delivery robots).
2. Semi-autonomous/Supervised (e.g. Mars rovers, humanoids).
3. Fully autonomous (e.g. robot vacuum cleaners, autonomous cars(?)).

Mobile Robots: State of the Art

Mars Rovers Spirit and Opportunity (NASA)

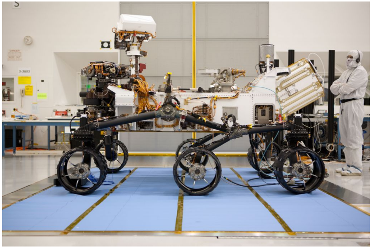


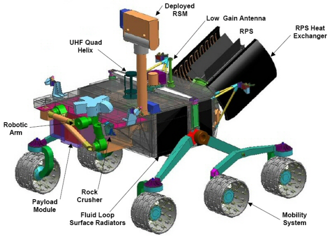


- Both had successful missions on Mars in starting in late 2004. Spirit went ‘silent’ in March 2010, and Opportunity finally in 2018.
- 1.6m long; 180kg. 9 cameras (Hazcams, Navcams, Pancams, microscopic).
- Remote human planning combined with local autonomy.
- Increased autonomy as mission progressed.

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 technology: e.g. Google car (now Waymo) `https://www.youtube.com/watch?v=B8R148hFxPw`
- Most car companies now have major autonomous driving projects. Other companies are developing 'autonomous taxi' services.

Mobile Robots: State of the Art

- Spot, from Boston Dynamics `https://youtu.be/wlkCQXHEgjA`.
- Five active stereo sensors give all around perception for localisation and mapping.
- Product officially launched in 2019 and aimed at industrial inspection applications.

Mobile Robots: State of the Art

Skydio: 'The Self-Flying Camera'

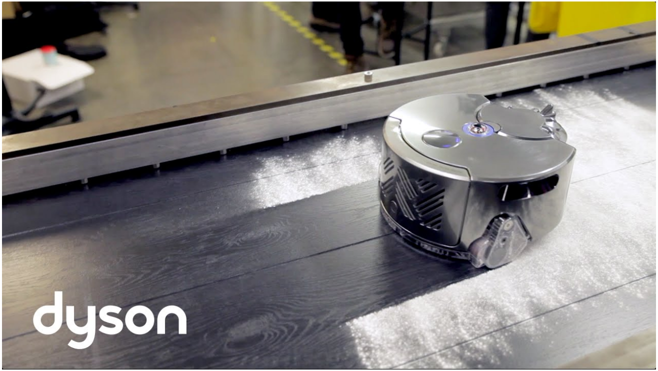
- Visual-inertial navigation and obstacle avoidance using multiple stereo camera pairs.
- Mobile NVidia processor onboard.
- https://www.youtube.com/watch?v=gsfkGlSajHQ

Mobile Robots: State of the Art

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

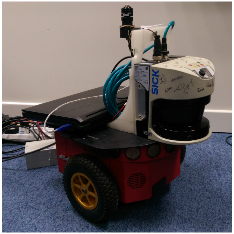
- 'Random bounce' movement style with short-range IR sensing.
- Over 10 million units sold!
- Later generation and competing products are now achieving precise navigation.
- http://www.youtube.com/watch?v=OMUhSBeIm40

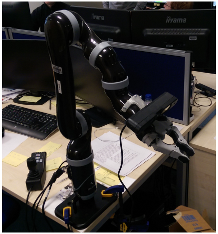
Dyson 360 Eye



- 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.
- `https://youtu.be/gZ3VV0O1Axo`

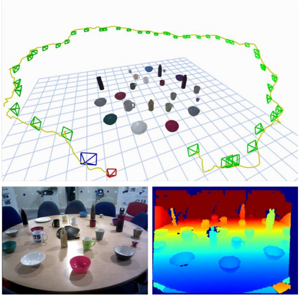
The Dyson Robotics Laboratory at Imperial College





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

NodeSLAM: Making maps using Neural Object Descriptors



- Sucar, Wada, Davison, Dyson Robotics Lab at Imperial College, 3DV 2020.
- Volumetric coded object models for four categories.
- Optimised against multi-view depth images using differentiable rendering.
- `https://youtu.be/zPzMtXU-0JE`

Robotics: Requirements

1. Essential geometry (vectors, rotations, trigonometry).
2. Essential probability theory.
3. Programming: you will write a lot of code.
4. Willingness to work with (build, adjust, calibrate, test) robotics elements from scratch!

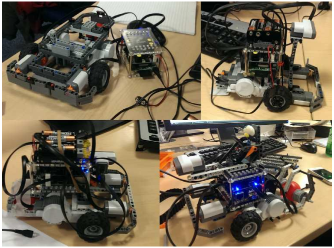
Robotics: Learning Outcomes

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 control, encoders, configurations and uncertainty in motion.
4. 2D coordinate frames for pose estimation and planning.
5. The use of sensors in reactive, behavioural programming.
6. Calibrating and robustifying sensors.
7. The essentials of probabilistic techniques in robotics; probabilistic localisation and mapping.
8. Local and global planning for wheeled robots.
9. Techniques for real-time robot programming.

Robotics: A Practical Course

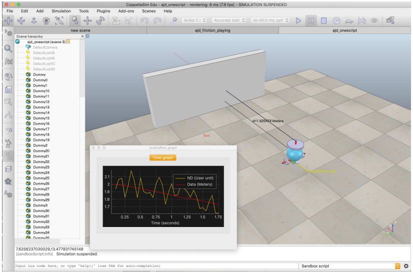
Usually:



This year we will work in **simulation**, but with very much the same ideology as in previous years:

- Mobile robotics from first principles (avoiding off-the shelf libraries!)
- Learning by doing.

Robotics in CoppeliaSim



Our practical work is based on the CoppeliaSim robotics simulator. This is a powerful and general purpose robotics simulation environment used in research, industry and education. It features:

- Efficient real-time 3D physics simulation.
- Easy to use Graphical User Interface for building and interacting with scene models.
- A wide range of built-in robots, sensors, scenes, furniture, etc.
- Fully integrated programming and customisation via scripts in Lua.

Simulation in Robotics

Simulation in robotics is more important than ever, and a crucial part of any robotics project in research or industry.

- Simulations get better all the time. They have an obvious use in early development of algorithms, checking for errors; but are now seriously used for testing and training algorithms for the real world (simtoreal).
- Is research in simulation 'doomed to succeed?' Some roboticists are still wary about any work not in the real world.
- But simulation allows us to push further and faster in some challenging research directions; e.g. reinforcement learning.
- See 'Rearrangement: A Challenge for Embodied AI', arXiv 2020. `https://arxiv.org/abs/2011.01975`
- RLBench, `https://sites.google.com/view/rlbench`

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. You will be set a practical task each week. Three of these (the schedule very clearly says which) will be *ASSESSED*.

- You will work in practical groups of from 2 to 4 students, and these groups will be fixed throughout term. Please let us know who is in your group via the wiki linked on the course website.
- 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, showing us some results on paper or on screen, or oral explanation of results.
- We will mark these exercises in face-to-face videoconference by visiting all groups *at the start of the subsequent 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 33% of the total marks available for the whole course, to reflect the fact that **it is a lot of work**. Also, the exam will be designed to tie in **very** closely with the coursework, and those members of groups that have made a good effort during term do very well on the exam.
- Previous years' exam papers are a very good guide to seeing what the style of questions will be, but every year the exam will change somewhat to reflect the current lecture and practical content of the course.

Robotics: Competition

In the final week of the course, 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!

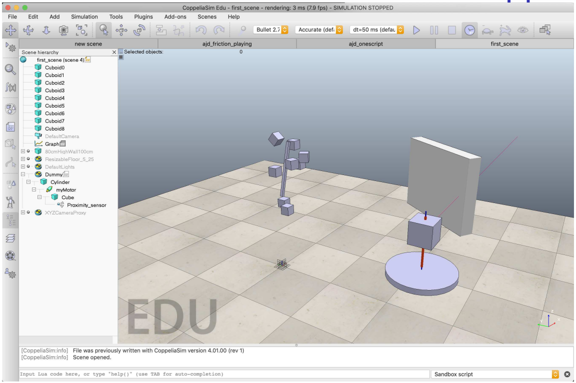
This year the competition challenge will be for fun/glory/learning and is not part of the coursework assessment.

See previous years at `http://www.doc.ic.ac.uk/~ajd/Robotics/`.

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/
- You should not need to buy any books, but if you want some more detail on probabilistic robotics in particular we can recommend the following:
  - 'Probabilistic Robotics', Sebastian Thrun, Wolfram Burgard and Dieter Fox

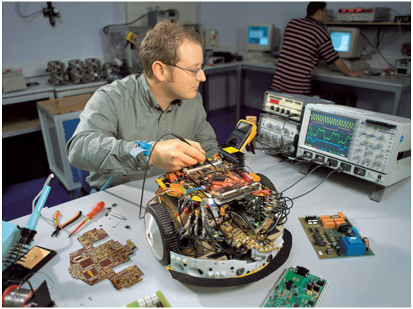
Week 1 Practical: Introduction to CoppeliaSim



- Goal: to introduce CoppeliaSim and what can can do, and make sure everyone is up and running with the software.
- First live practical, this Friday from 4–6pm.
- Organise yourselves into groups and tell me about your preference of in-person vs. remote.
- Practical sheet and example code now available from the course website.

Robot Floor Cleaner Case Study

- If you are interested in some good motivation for mobile robotics and product thinking, see our case study tutorial on the website (in the Additional Handouts section lower down).



- 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

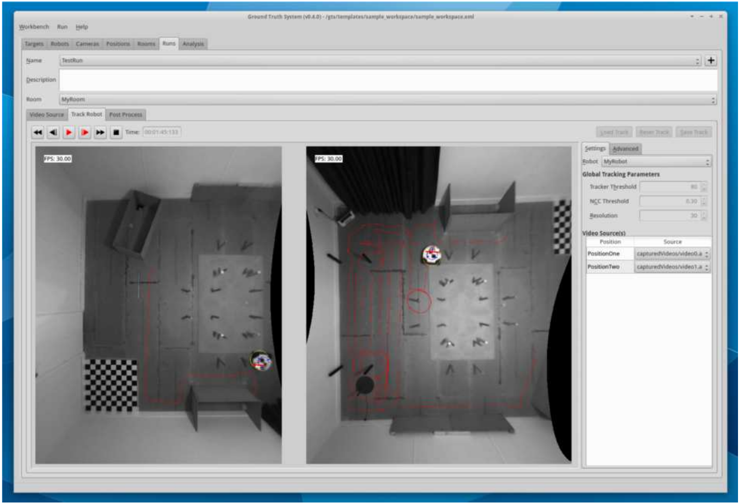
Navibot

Mint

Neato

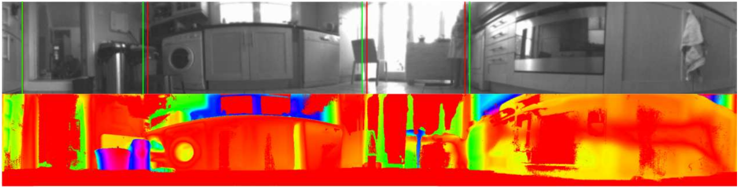
Roomba (iRobot), floor coverage
`http://www.youtube.com/watch?v=0MUhSBeIm40`
Mint Floor Cleaner (Evolution Robotics)
`http://www.youtube.com/watch?v=6Cf55mIaNGw`

Evaluating Robot Floor Cleaners



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

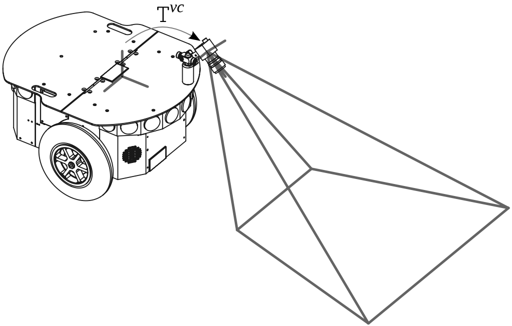
Getting More From Omnidirectional Vision

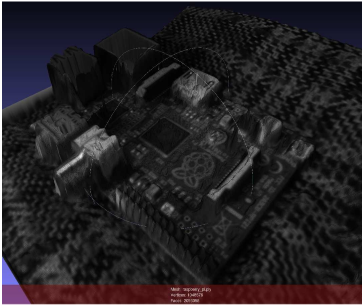


GT Area	$7.28\,\mathrm{m}^2$
Est. Area	$6.71\,\mathrm{m}^2$
Overlap	$92.21\,\%$

- Fitting ‘box’ room models to omnidirectional depth reconstruction.
- Lukierski, Leutenegger and Davison, 2016.

Real-Time Height Map Fusion from a Single Camera





(Zienkiewicz, Davison, Leutenegger, 2015/2016)

- Dense fusion from a moving robot-mounted camera to identify free space and obstacles.
- `https://youtu.be/3NQqeRcSsCw`
- Real-time multi-scale fusion using adaptive level of detail, 3DV 2016.