COMP20170
Introduction to Robotics

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Lecture Plan

- Most weeks will consist of 1 hour lecture (Thursday 1-2pm) and a compulsory 2 hour lab (Friday 2-4pm).
- Please use csmoodle.ucd.ie week by week for details.
- Enrolment key: UCDCOMP20170

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.

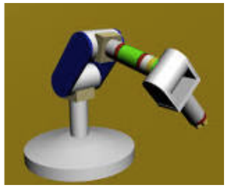
Robot for home

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

Forward kinematics refers to the use of the **kinematic** equations of a robot to compute the position of the end-effector from specified values for the joint parameters. The **kinematics** equations of the robot are used in robotics, computer games, and animation.



In robotics, **inverse kinematics** makes use of the **kinematics** equations to determine the joint parameters that provide a desired position for each of the robot's end-effectors. Specification of the movement of a robot so that its end-effectors achieve the desired tasks is known as motion planning.

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

Mobile robots

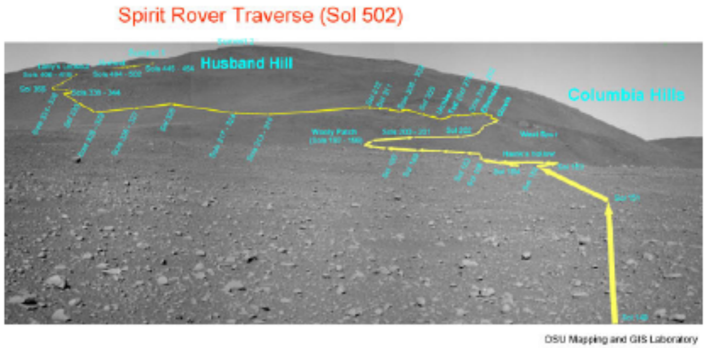
- A mobile robot needs actuation for locomotion and sensors for guidance.
- Ideally untethered and self-contained: power source, sensing, processing on-board (return to charging station? on-board computing? outside-in sensing?)
- Required competences include:
  - Obstacle avoidance
  - Localisation
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

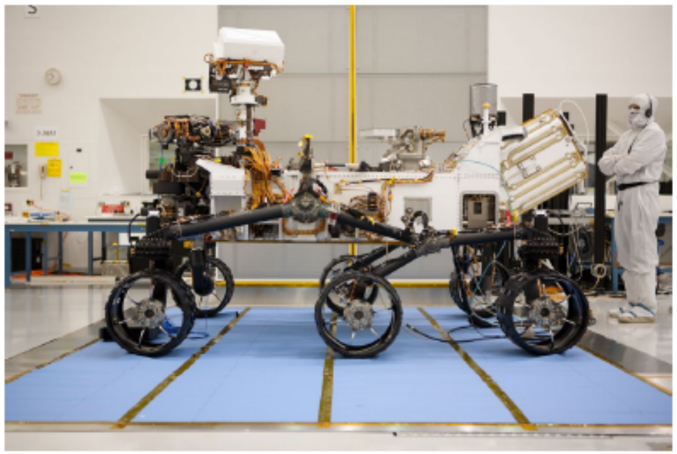
Mars Rovers Spirit and Opportunity (NASA)

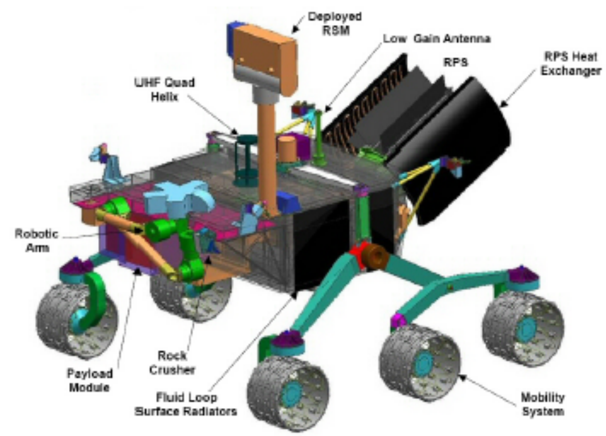


- Both had successful missions on Mars in starting in late 2004. Spirit went ‘silent’ in March 2010; Opportunity is still operational and has to date covered more than 34km.
- 1.6m long; 180kg. 9 cameras (Hazcams, Navcams, Pancams, microscopic).
- Remote human planning combined with local autonomy.
-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

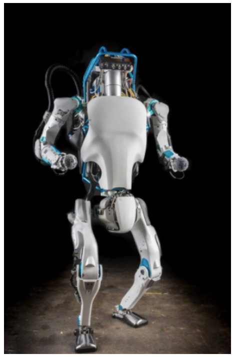
- Several high-performance research humanoids now presented (since pioneering work by Honda in 1990s).
- Impressive movement but so far limited sensing and autonomy.

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

Best Humanoid Robots in 2017



Making its debut in 2013 at a competition conducted by Defense Advanced Research Projects Agency, ATLAS is capable of opening doors, balancing while walking on snow, navigating, avoiding terrains etc. Built by Alphabet's company Boston Dynamics, Atlas was designed to perform disaster recovery operations in locations that are unsafe for human beings. The newer version of Atlas is completely mobile whereas the previous version was sedentary tied to a computer machine. Boston Dynamics has the reputation of building robots that are capable of running faster than Usain Bolt. Atlas is not just one of the robots in Google's show case as the company has invested heavily in designing man-like machines.

Advanced Step in Innovative Mobility, abbreviated as Asimo, is the world's first robot. It was designed by Hondo and introduced to the world in 2000. This is also the world's first two legged robot and Honda has been working on this since 1986. The first two legged version of the robot EO in 1986 walked slowly taking a time of 5 seconds between two steps. Since 1993, Honda focused to transform its moving robot into a humanoid one and as a result the first Asimo was developed in 2000. Today, Asimo has become more intelligent and responsive that can interact with human beings by recognizing voices, faces and interpreting human gestures. It can also sense moving objects, their distance and direction.

Have you watched Transformers and wondered if this can be ever a reality? Wake up and smell the coffee. Kuratas is a military robot that is rideable by a user sitting inside its cockpit or operated from outside using a remote control. The gargantuan mecha weighs 4500 kg and is loaded with ammunitions to attack the enemy. The irony is the user can start firing the enemy targets with a smile. This feature has been given the name 'The Smile Shot'. It's important that the user doesn't inhale any laughing gas before boarding Kuratas. The robot was available for purchase at Amazon Japan priced at more than $ 1 million or ￥120,000,000 . As it is only a starter kit, the order will not include the arms for the robot and they have to be purchased separately by paying another huge sum. Kuratas was built by Suidobashi Heavy Industry and was introduced in 2012 as the "world's first giant boarding robot".

Romeo

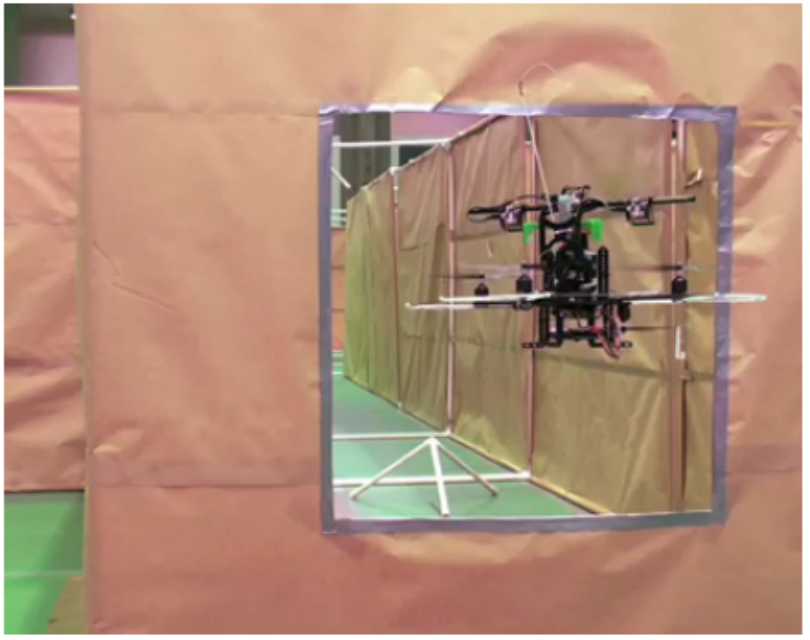
Built by Aldebaran Robotics to help elderly patients and disabled people, Romeo was a part of French research and development project funded by French Ministry of Economy and Finance. Romeo is in its development stage and is supposed to identify obstacles, carry objects and patients in need, and monitor their health.

Romeo, which is 1.4 meters high and weighs 40 kg, is considered to be an enhanced version of Nao. Anyhow, the engineers had to build a completely different humanoid.

Aldebaran is expecting to have Romeo assisting in old age care facilities by 2017 or the latest by 2019. The robot will be available to the project partners at a cost of 250,000 euros. An improved version will be available for nursing homes and hospitals and at a later stage to individuals as well.

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

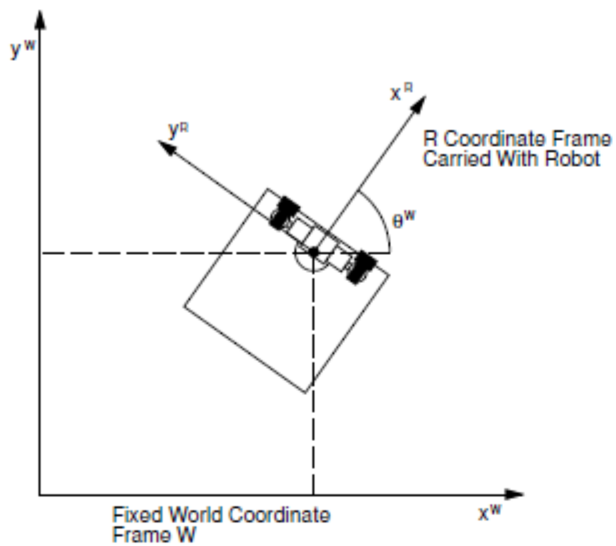
- Wheels are most common, in various configurations.
- Legs increase mobility, but with much extra complication.
- Robot size affects power requirements/efficiency, actuator specifications.

Autonomous Underwater Vehicle

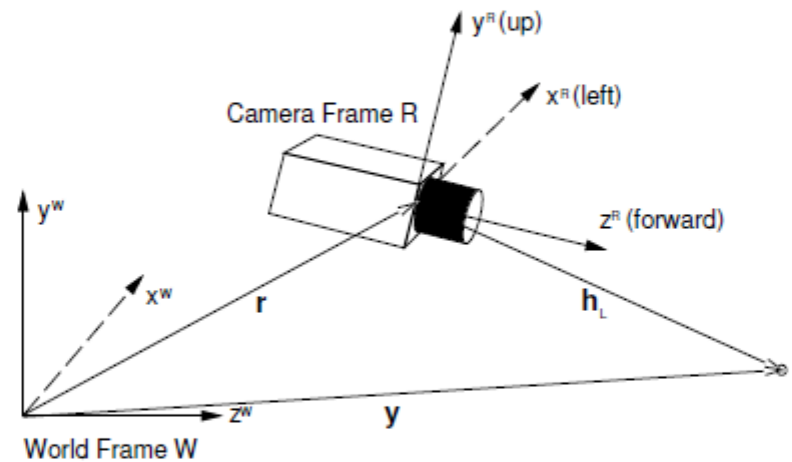
Unmanned Aerial Vehicle

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:

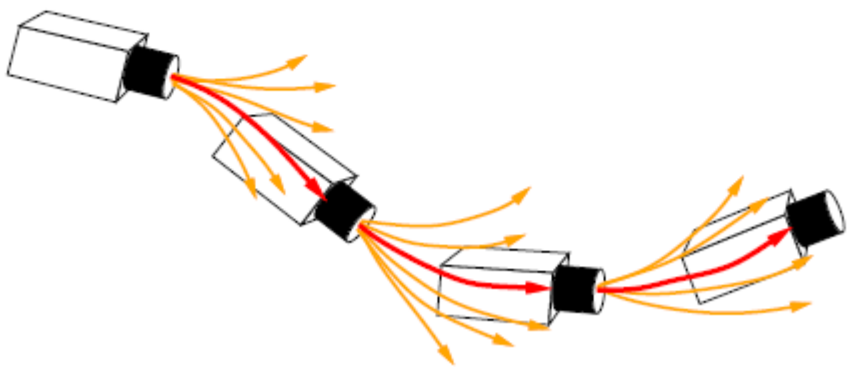
- Wheel odometry (encoders, or just checking voltage level and time).
- Tilt sensors (measure orientation relative to gravity).
- Gyros (measure angular velocity).
- Compass.
- Internal force sensors (for balance).

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.

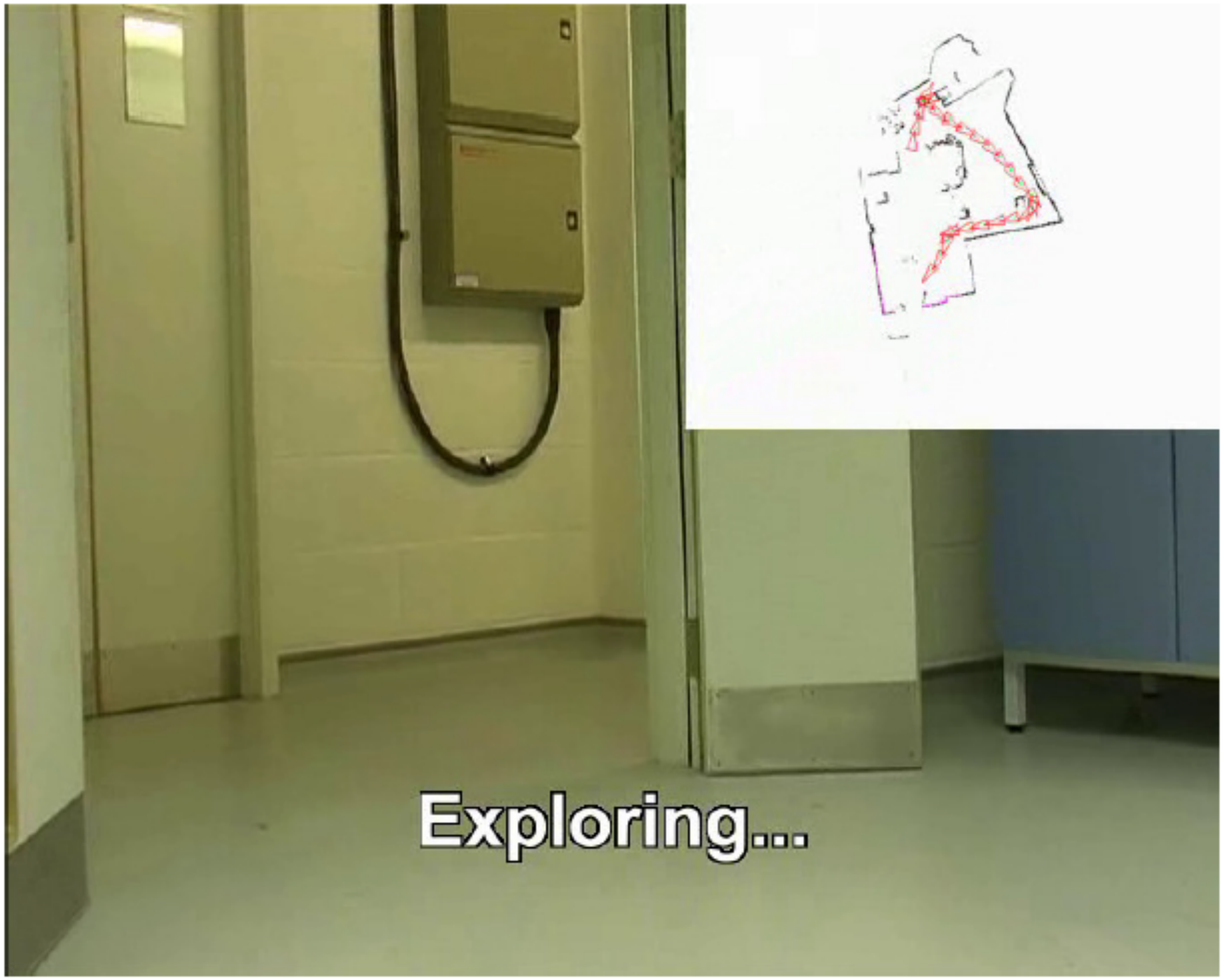


- The way to resolve drift is to build a *map* of the static world.

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.

What is SLAM?

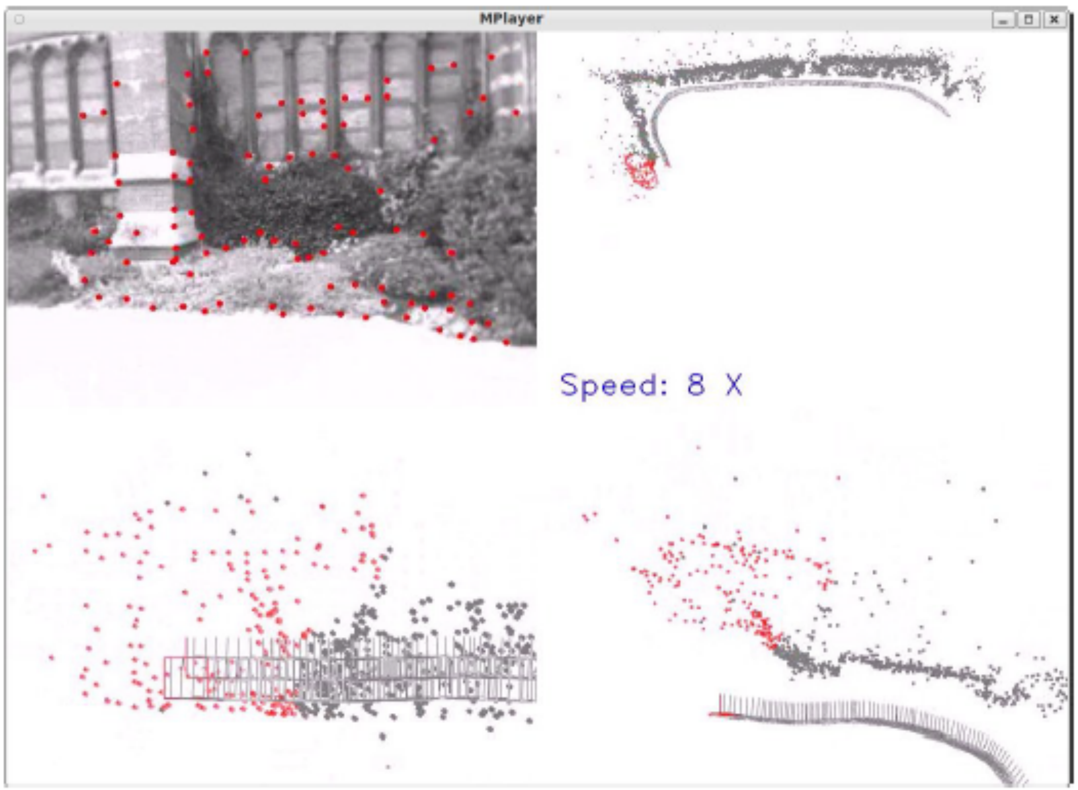
- Mapping, building a map of the environment which the robot is in, and
- Localization, navigating this environment using the map while keeping track of the robot’s relative position and orientation.
- Applications for autonomous (self-controlled) mobile robots with applications from driverless cars through to robotic vacuum cleaners.
- SLAM techniques can also be applied to augmented reality (AR), for example, Snapchat’s facial tracking filters or Sony’s AR effect.

How does visual SLAM work?

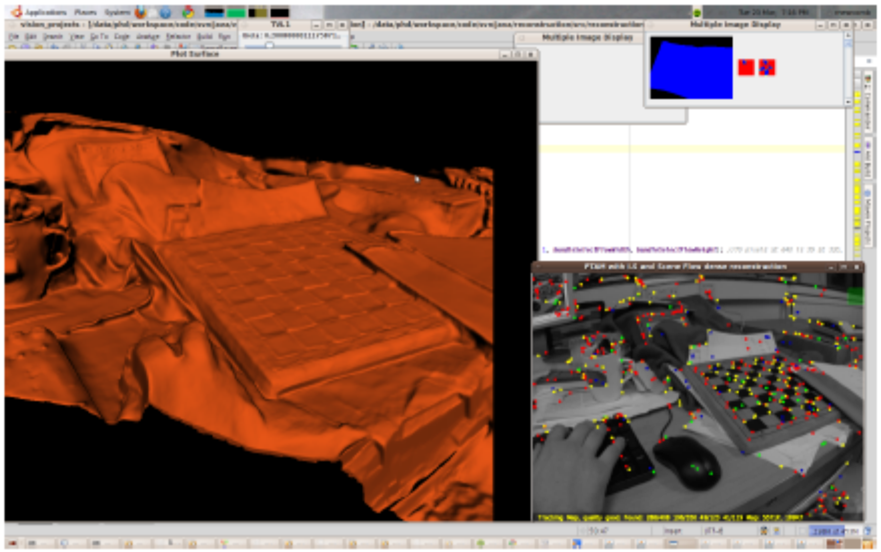
- Step 1: Identification of many significant and distinct landmarks, usually lines (e.g. edges of a table or wall) and corners, from each image from an image frame of the video from the camera.
- Step 2: (assuming that the environment doesn't change between each frame), the landmarks in successive or close frames are associated with 3D objects in the camera's environment.
- Step 3: The landmarks are then matched together to re-associate with objects already seen and the data is used to generate information about both the camera's position (**localization**) and a map of the environment (**mapping**).
- Step 4: With a sizable chain of video frames and landmarks from them, SLAM algorithms use the data to **infer estimates of a path** on which the camera has moved, and the positions in 3D space of all of the objects and features in the environment that the camera has observed. It also estimates the position of the camera relative to other features in the environment.
  - In the operation of some methods and algorithms, before a mobile robot is released to roam freely and implement the steps above, **some initial data about the environment can be injected to kick start the process** . There is a wide range of different algorithms which work to solve these problems with a single visual camera.
  - An Extended Kalman Filter (EKF) algorithm keeps track of the uncertainty of the robot's position and the position of landmarks on the map. It uses this cumulative data to perform calculations which determine the updated best estimate of the positions of the robot and of objects on the robot's 3D map. This means that the errors between the robot's map and the real environment do not build up and "drift apart".

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.

COMP20170
Week 1-4

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

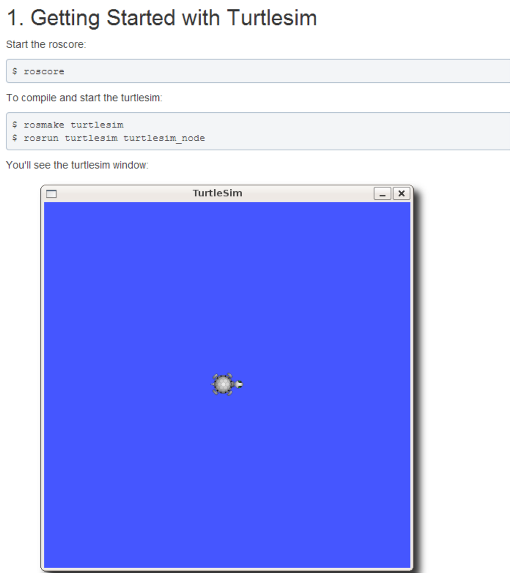
- Wheeled configurations and uncertainty in movement.
- Using simple sensors to implement reactive behaviours.
- Investigating the characteristics of advanced sensors like sonar.
- Implementing a probabilistic localisation filter…?

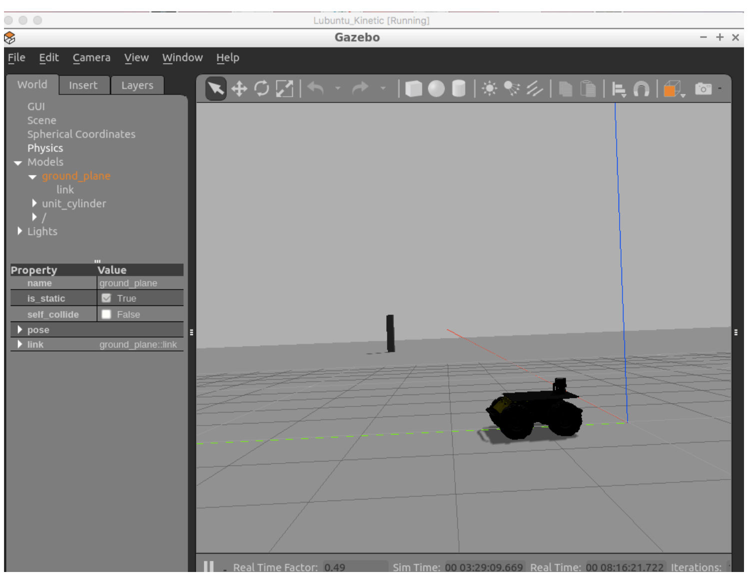
COMP20170
Week 4-8

Image courtesy KUKA Roboter GmbH.

- **Description of position and orientation**
- Forward Kinematics of manipulators
- Inverse Kinematics of manipulators
- Velocities, static forces, singularities
- Dynamics
- Trajectory generation
- Manipulator design and sensors
- Linear position control
- Nonlinear position control
- Force control

COMP20170
Week 8-12





In groups you will use the **ROS (Robot Operating System) Gazebo** and **TurtleSim** to :

- Implement an "obstacle avoidance" algorithm.
- Implement a "go to target" algorithm.
- Implement a "wander" algorithm.
- Implement an "explore" algorithm.
- Implement a "search" algorithm.
- Implement algorithm to detect objects that may be present in the environment.

COMP20170: Coursework and Assessment

- The coursework component is based on accumulative assessment of achievement in the practical sessions and one submission of a written report. From next onwards you will be set a number of practical tasks, 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 4 or 6 depending on total numbers; **Students should 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.
- Practical Assessment (**Group work**):
  - EV3 (3 Assignments): 35%
    - Movement (10%)
    - Behaviour (10%)
    - Kinematics (15%)
  - ROS (2 Assignments): 30%
  - Engineering Journal (**Group work**): 15%
- One written essay **(Individual essay)**: 20%
- All members of a group will receive the same mark for the group assessment by default (unless there is evidence that indicate certain members are not doing their share of work).
- No Final Exam Paper

COMP20170

- 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.

Engineering Journal

- Weekly logs have to be kept from each group
- We will follow the CMU curriculum for the lab the first couple of weeks: http://www.education.rec.ri.cmu.edu/previews/ev3_products/robotc_ev3_curriculum/

Essay Assignment
Deadline: Week 12 (20%)

- Select a Robot of your choice that has been implemented the last 5 years and within an essay of **max 2500 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