Autonomy: Localisation

Prof. Mirko Kovač
Dr. Kevin Holdcroft
Laboratory of Sustainability Robotics
EPFL, Switzerland

Learning goals

- Understand how robots are able to locate themselves in the environment
- Discuss how absolute positioning systems function
- Understand basic sensors used for localisation
- Explain the basics of computer-vision based localisation

Goal

- Understand how the graphs on the right are generated

1) https://www.youtube.com/watch?v=puyRbPtPyXw

Overview – Localisation

- To move, robot needs to know
  - Where it is
    - Positioning
  - Where it's going
    - Motion planning

- Challenges
  - Terrain
  - Moving obstacles
  - Computation time
  - *Everything*

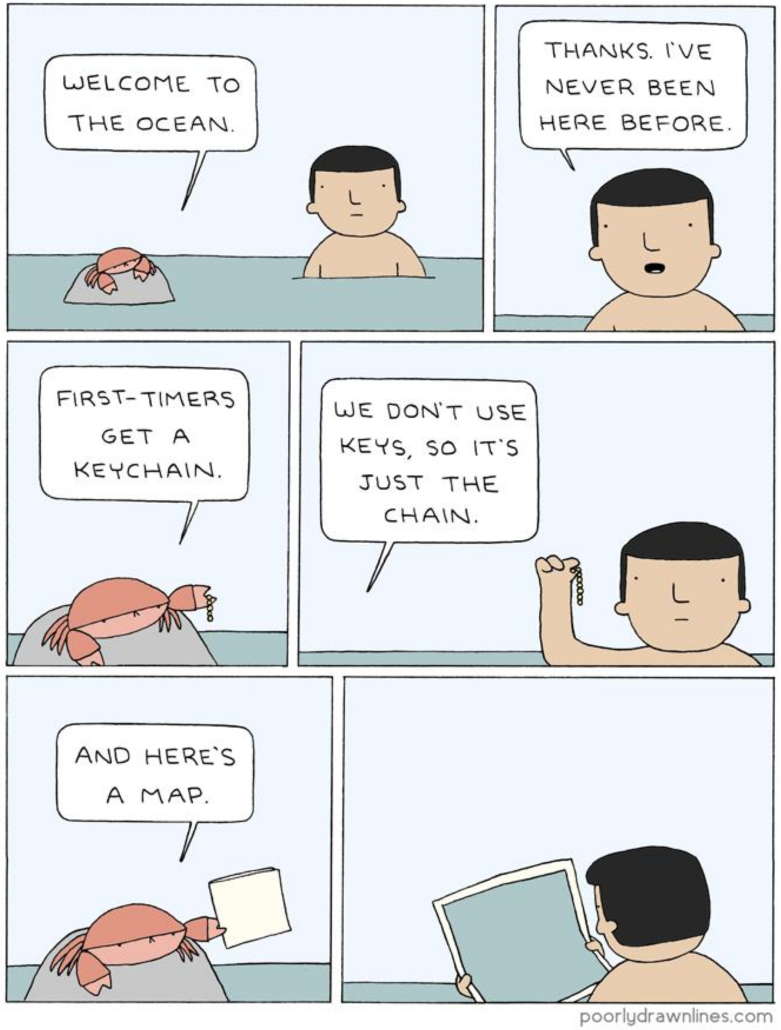
1) https://img.freepik.com/premium-photo/yellow-robot-with-large-goggles-is-looking-map-yellow-background_14117-576310.jpg

Overview – Positioning

- Absolute vs relative positioning

- Absolute positioning
  - Exact location on globe
  - E.g., GNSS / GPS

- Relative positioning
  - Relative to another reference
  - E.g., Distance since power on



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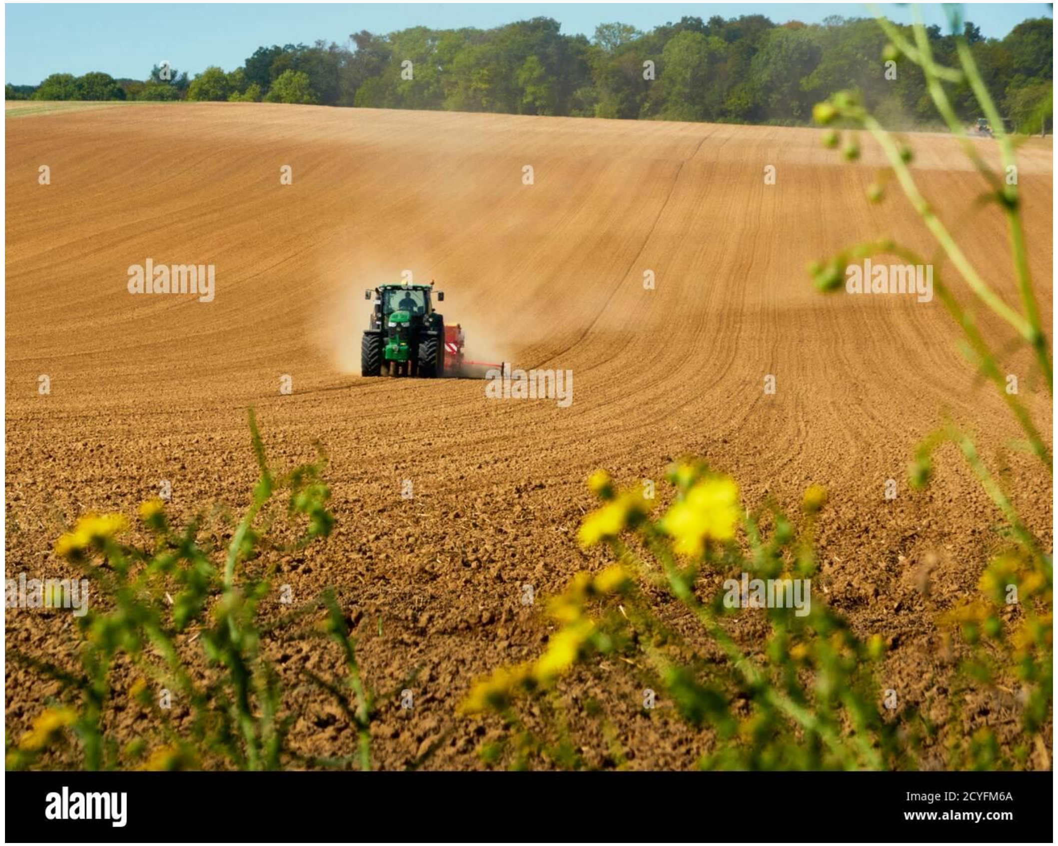
1) https://poorlydrawnlines.com/comic/welcome/

Absolute positioning

- Needed when no "features" to detect
  - E.g., empty field

- Sensors
  - GNSS



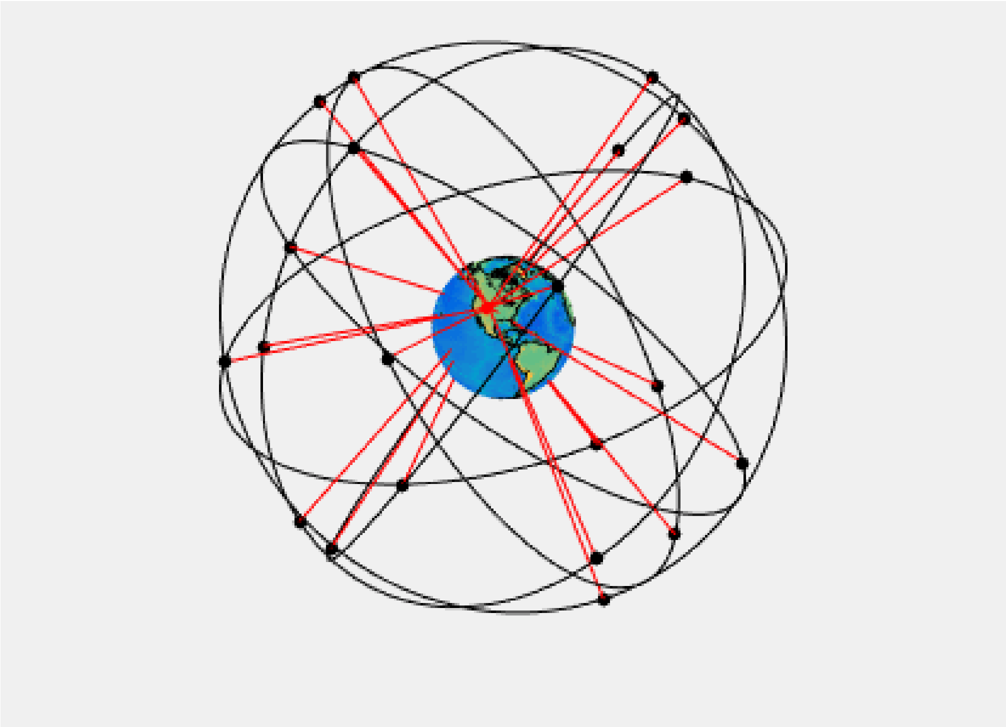
1) https://www.alamy.com/tractor-plowing-a-huge-sandy-empty-field-blurred-yellow-flowers-in-the-foreground-image378358578.html

Global Navigation Satellite Systems (GNSS)

- Network of satellites in orbit

- Used to pinpoint location on the planet
  - Good for several meters

- Different systems:
  - Galileo (EU)
  - GPS (USA)
  - GLONASS (Russia)
  - BeiDou (China)



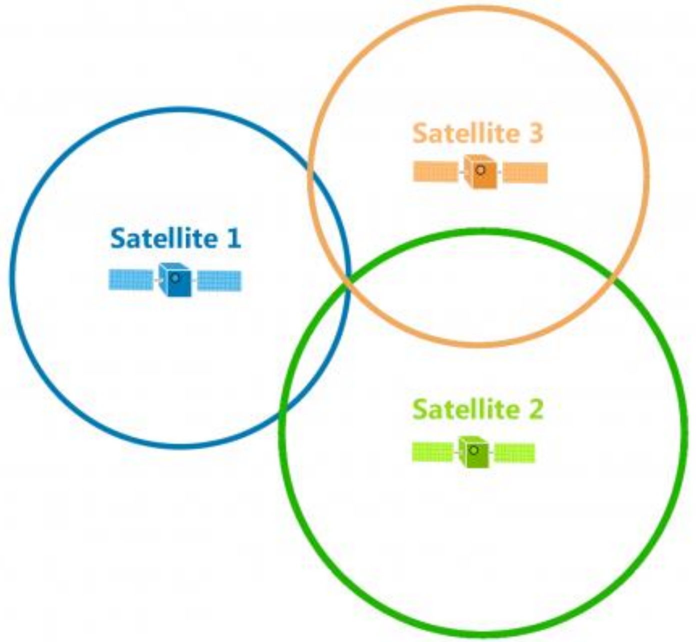
1) https://en.wikipedia.org/wiki/Global_Positioning_System

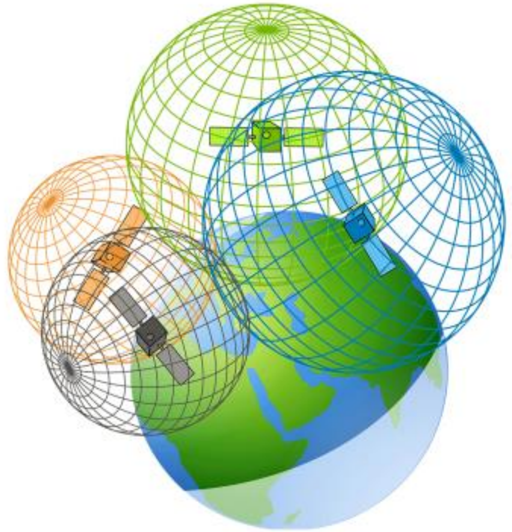
GNSS working principles

- Satellites in geostationary orbits
  - Every satellite sends a ping every second
    - Time synchronised

- Relative time difference between received signals
  - Relative distance between satellites

- Trilaterate relative distances for location
  - Device needs to see 4 different satellites

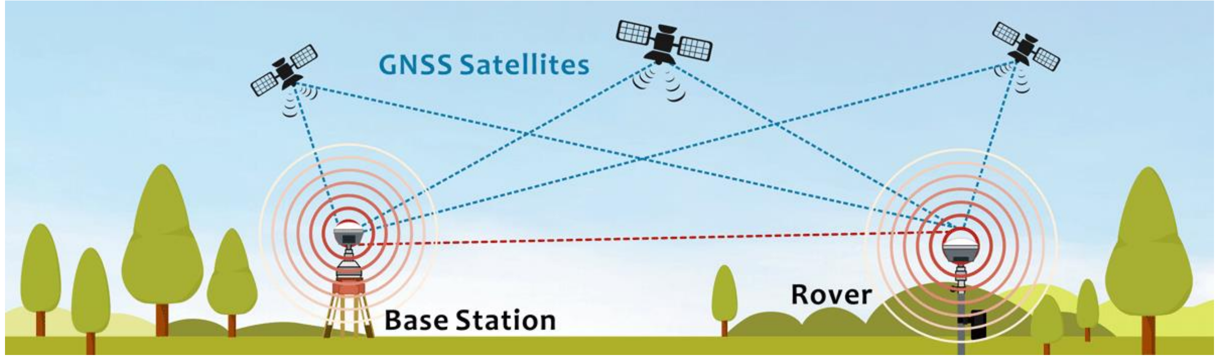


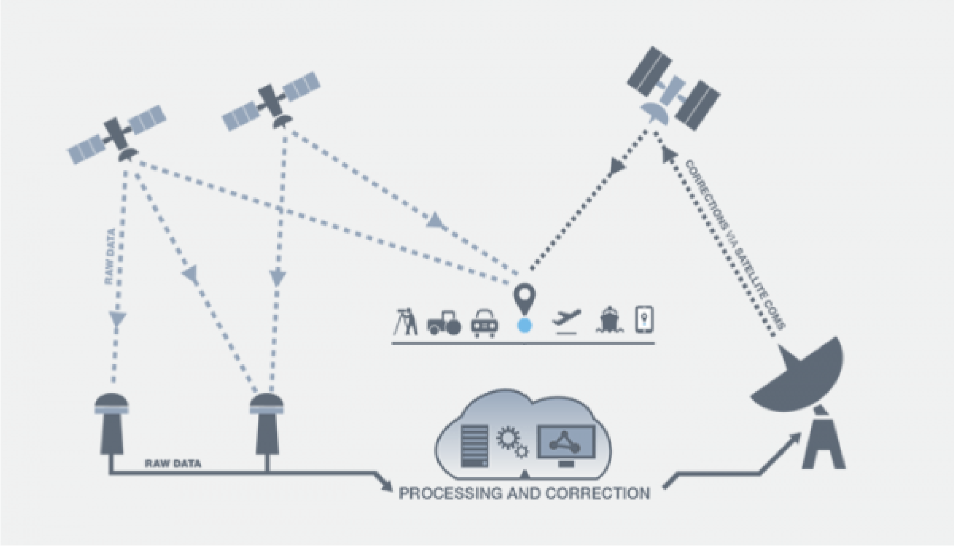


1) https://gisgeography.com/trilateration-triangulation-gps/

Improving GNSS

- Ping from satellites effected by atmosphere conditions
  - Causes drift / mismeasurement
- Real-time kinematic (RTK) technology
  - Base station in known location
  - Corrects for weather drift
- Satellite-based Augmentation System (SBAS)
  - RTK to calculate errors
  - Sends error to a satellite, then publishes error corrections to GNSS devices
  - WAAS, EGNOS (EU)





1) https://www.unictron.com/wireless-communications/tpost/rtk-gnss/
2) https://adenilsongiovanini.com.br/blog/sbas-o-que-e-e-para-que-serve/

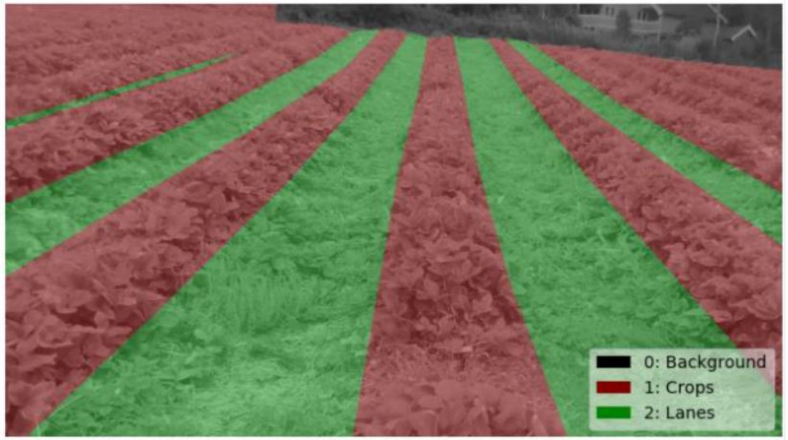
Relative positioning

- Positioning according to a reference
  - E.g., distance since power on
  - E.g., distance moved relative to that tree over there

- Internal vs external sensing
  - Internal: measure the internal state of the system
  - External: make observations outside the system

- Sensors
  - Accelerometers, IMUs, encoders
  - Lidar, sonar, cameras

(a) Actual RGB image



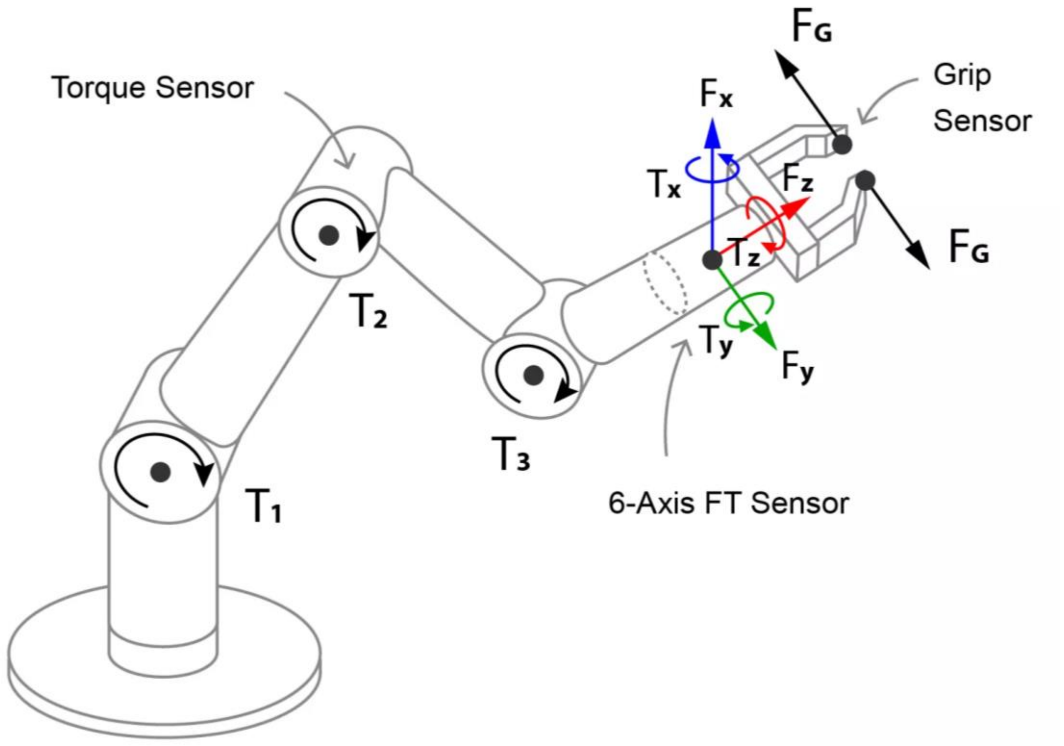
(b) Annotated Image

1) https://www.mdpi.com/1424-8220/20/18/5249

Internal sensing

- Measures innate motion properties of the system
  - E.g., walking in a room with a blindfold

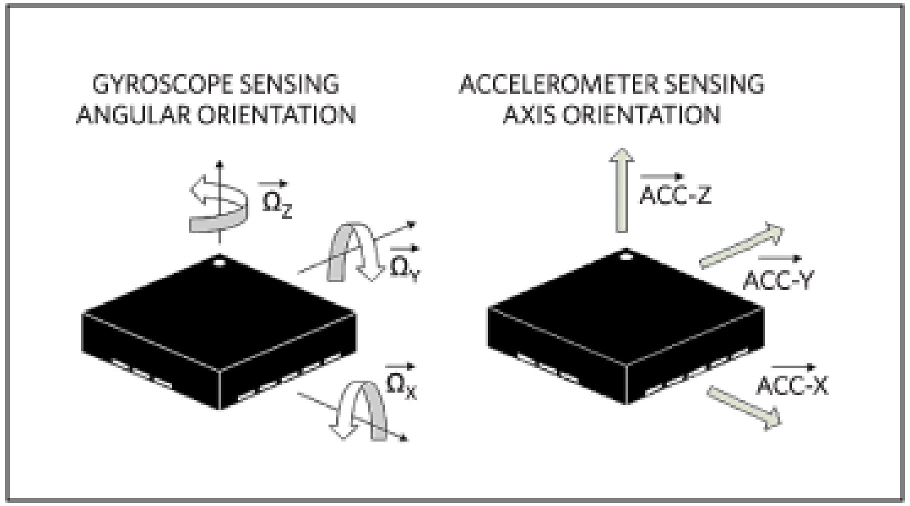
- Sensors
  - **Accelerometers + Gyroscopes**
  - **Motor encoders**
  - Force / Torque sensors (on joints)

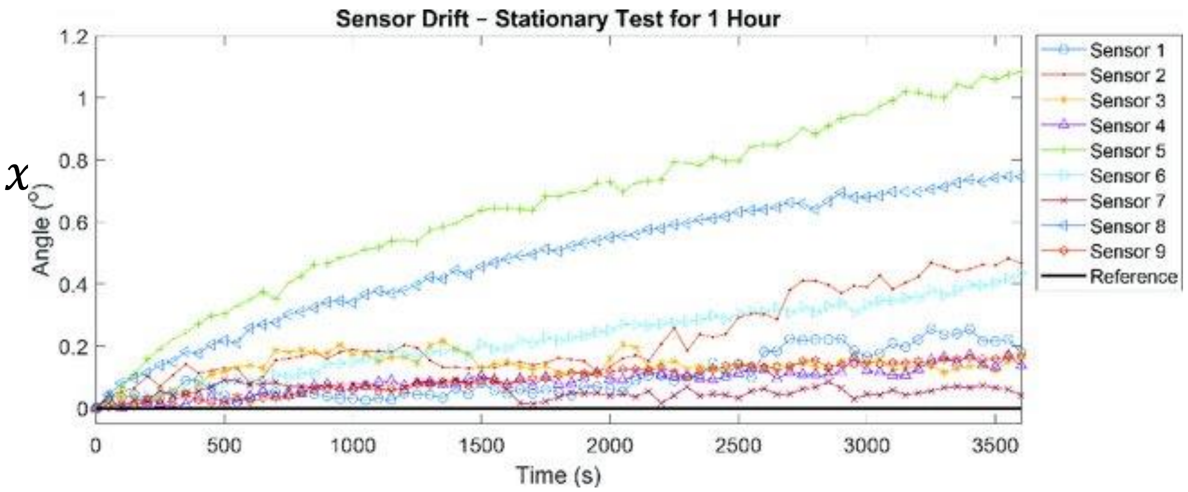


1) https://reachrobotics.com/blog/force-and-torque-ft-why-are-they-of-interest-in-robotics/

Accelerometers and gyroscopes

- Accelerometers vs gyroscopes
  - Accelerometer - Measures changes in velocity (acceleration)
  - Gyroscope - Measures *angular rotation*
- Inertial measurement unit (IMU)
  - Combined accelerometer and gyroscope
- Challenge – Measuring position drifts
  - Acceleration to position: $\frac{d}{dt}\frac{d}{dt}\ddot{x} = \frac{d}{dt}\dot{x} = x$
  - Angular rotation to rotation: $\frac{d}{dt}\dot{r} = r$
  - *Each integration can add error from computation rounding errors*





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1) Hislop J, Isaksson M, McCormick J, Hensman C. Validation of 3-space wireless inertial measurement units using an industrial robot. Sensors. 2021 Oct 15;21(20):6858.
2) https://www.analog.com/en/resources/technical-articles/accelerometer-and-gyroscopes-sensors-operation-sensing-and-applications.html

Motor encoders

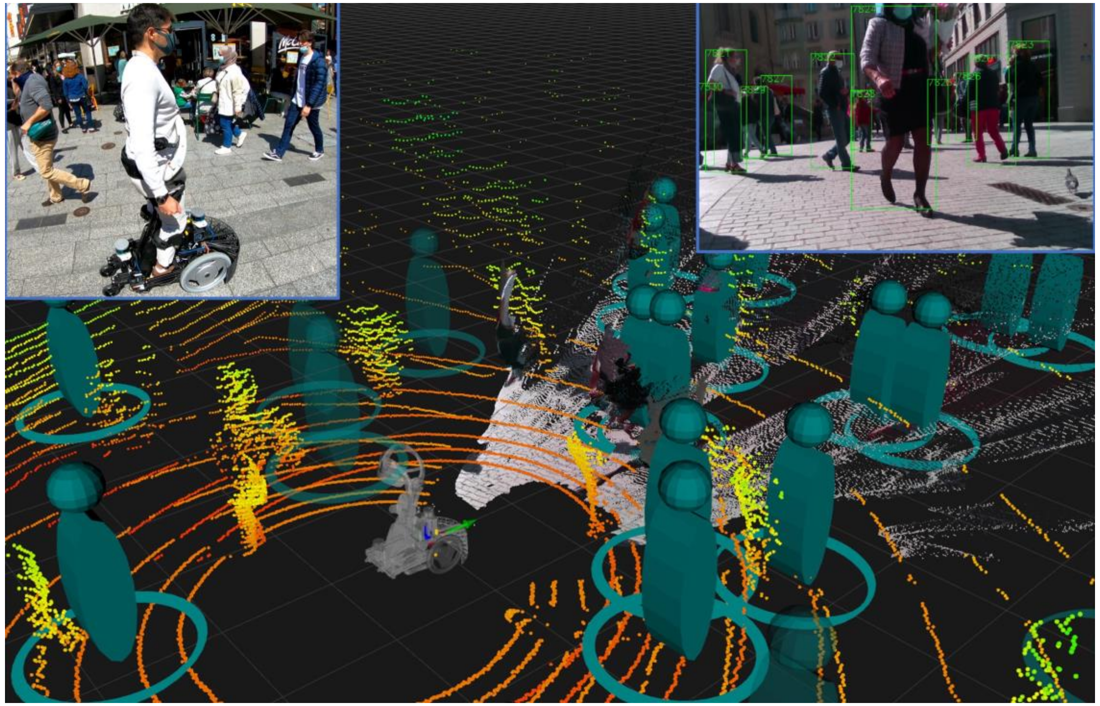
- Measures how much wheel has turned
- Given size of wheel
  - Amount of rotation corresponds to wheel circumference
  - How speedometer traditionally works in cars
- Challenge:
  - Slipping
  - Wheel changing size (tire pressure)

1) https://www.amazon.ca/Distance-Measuring-zozen-Collapsible-Industrial/dp/B08LN198TG

External sensing

- Requires *features* for reference
  - Something which stands out in the environment
  - I.e., something to *track*

- Sensors
  - **Lidar**
  - **Ultrasonic sensors**
  - **Cameras**
  - Mechanical feelers



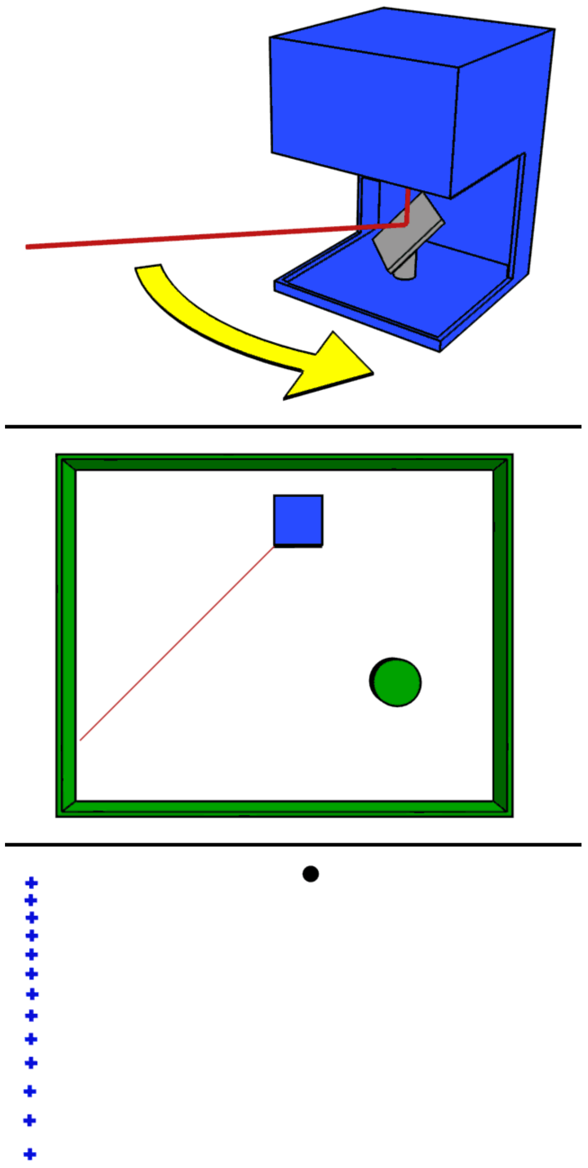
1) https://ieee-dataport.org/open-access/3d-point-cloud-and-rgbd-pedestrians-robot-crowd-navigation-detection-and-tracking

Lidar

- **Li**ght **D**etection **a**nd **R**anging

- Laser rangefinder to get distances
  - Scans laser across 2D plane
  - Produces a discrete scan of distances

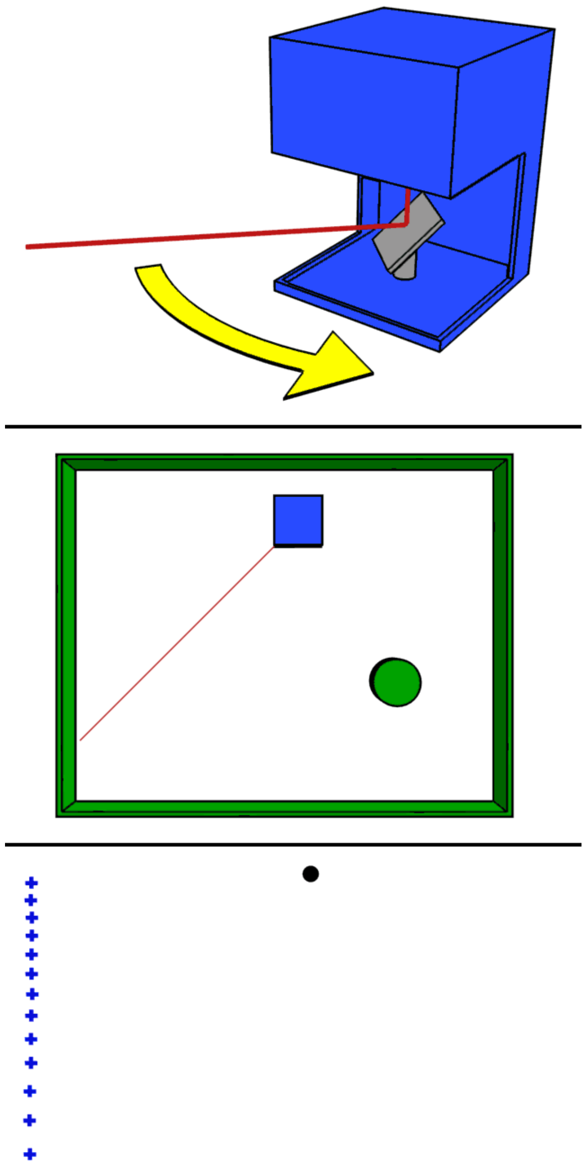
- Long range, but discrete points
  - Very different technologies
    - Some now integrated in smartphones



1) https://en.wikipedia.org/wiki/Lidar

Lidar (2)

- Pros
  - Precise
  - Accurate
- Cons
  - Bulky, expensive
    - Note: New tech has reduced significantly
  - Difficult to make 3D
    - 3D limited to a few degrees up/down
- Uses
  - Staple in robot positioning



1) https://en.wikipedia.org/wiki/Lidar

Lidar (3)

1) https://www.youtube.com/watch?v=IQJL3htsDyQ

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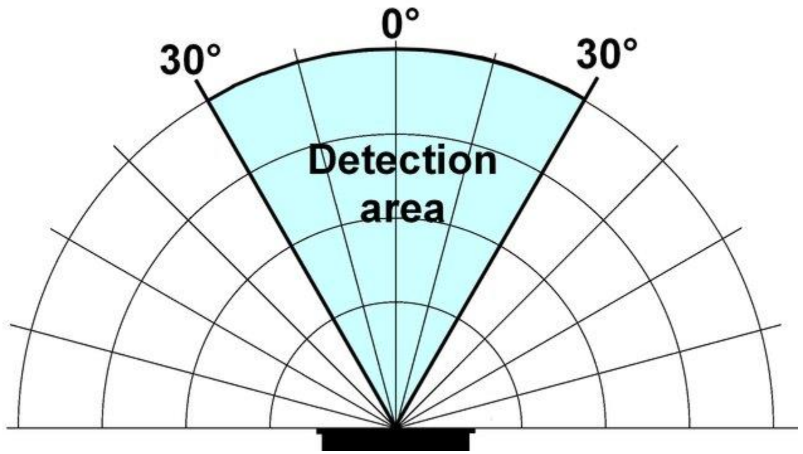
Ultrasonic sensor

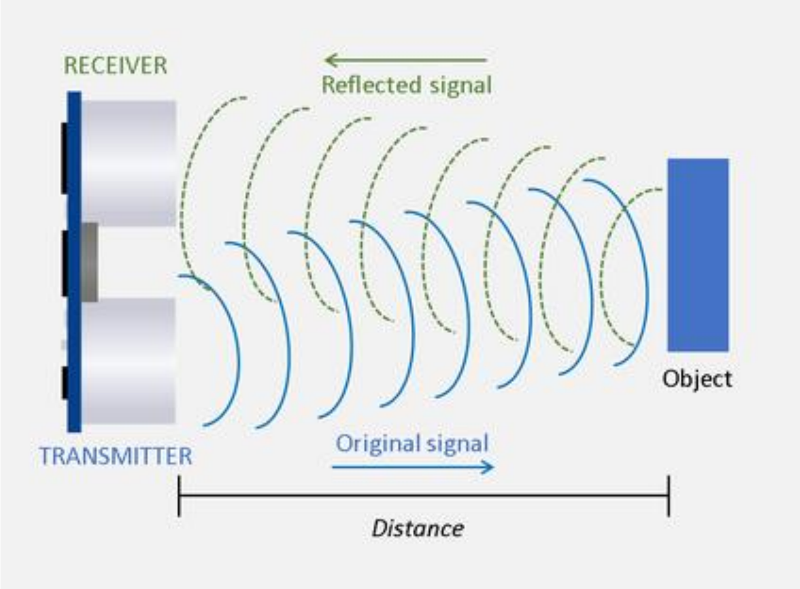
- Sends pulse of ultrasonic sound
  - Reflects off of closest object
  - E.g., what bats do
- Measure time between transmit and receive
  - Time * speed of sound = 2*distance
- Output pattern: conical
  - *Detects closest object in cone*



1) https://maxbotix.com/blogs/blog/how-ultrasonic-sensors-work;
2) https://www.researchgate.net/publication/326878711_Design_of_an_immersive_simulator_for_assisted_power_wheelchair_driving/figures?lo=1

Ultrasonic sensor (2)

- Pros
  - Cheap
  - Robust to lighting changes
- Cons
  - Short range
  - Easily obstructed
    - E.g., snow, dirt
  - Crosstalk
    - I.e., one sensor picks up other's pulse
- Uses
  - Parking sensors
  - Factory object detection



1) https://stelltron.co.za/product/ultrasonic-ranging-sensor/

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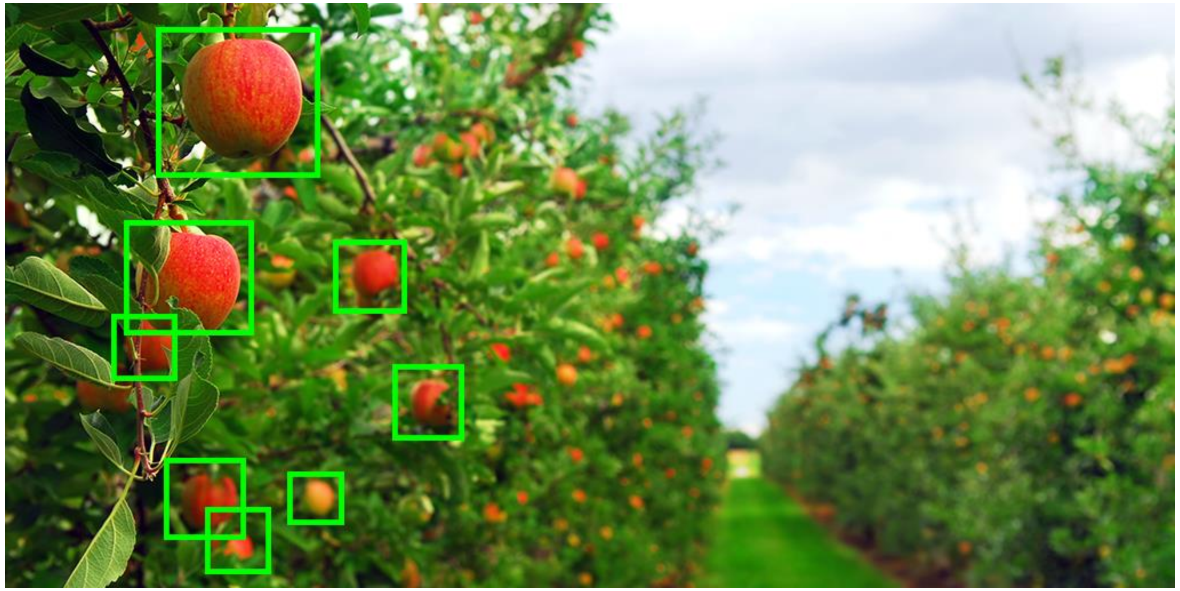
Cameras

- Pros
  - Ubiquitous
  - Continuous
  - Cheap

- Cons
  - High computation power
  - Lighting conditions

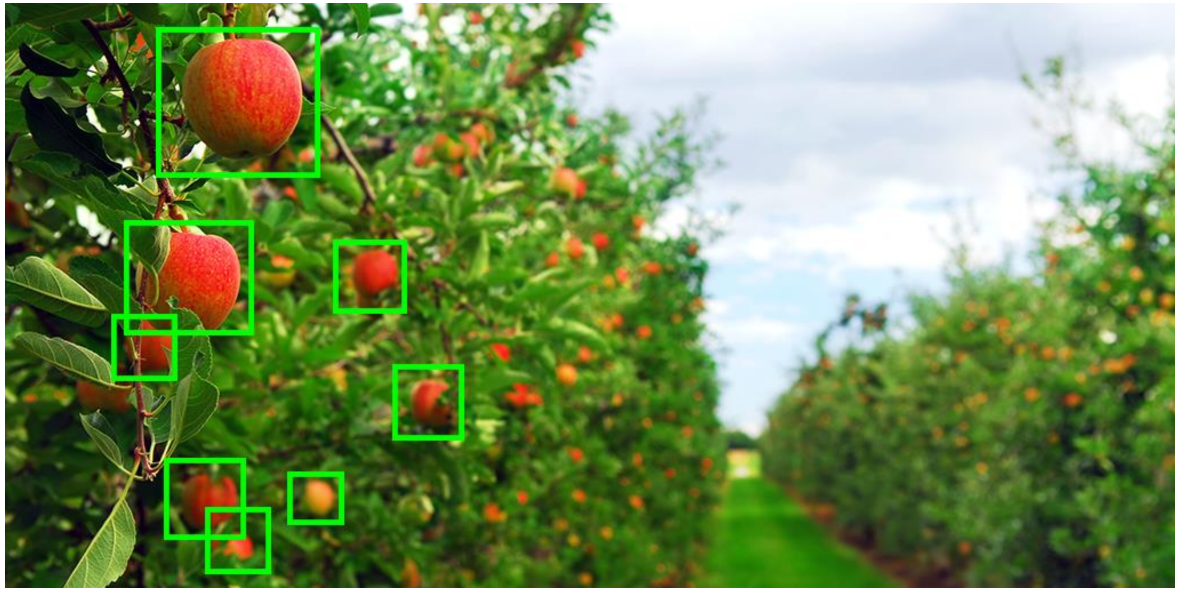
- *How to get a 3D image from a camera?*



1) https://www.croptracker.com/blog/computer-vision-in-agriculture-part-1.html

Steps to 3D understanding

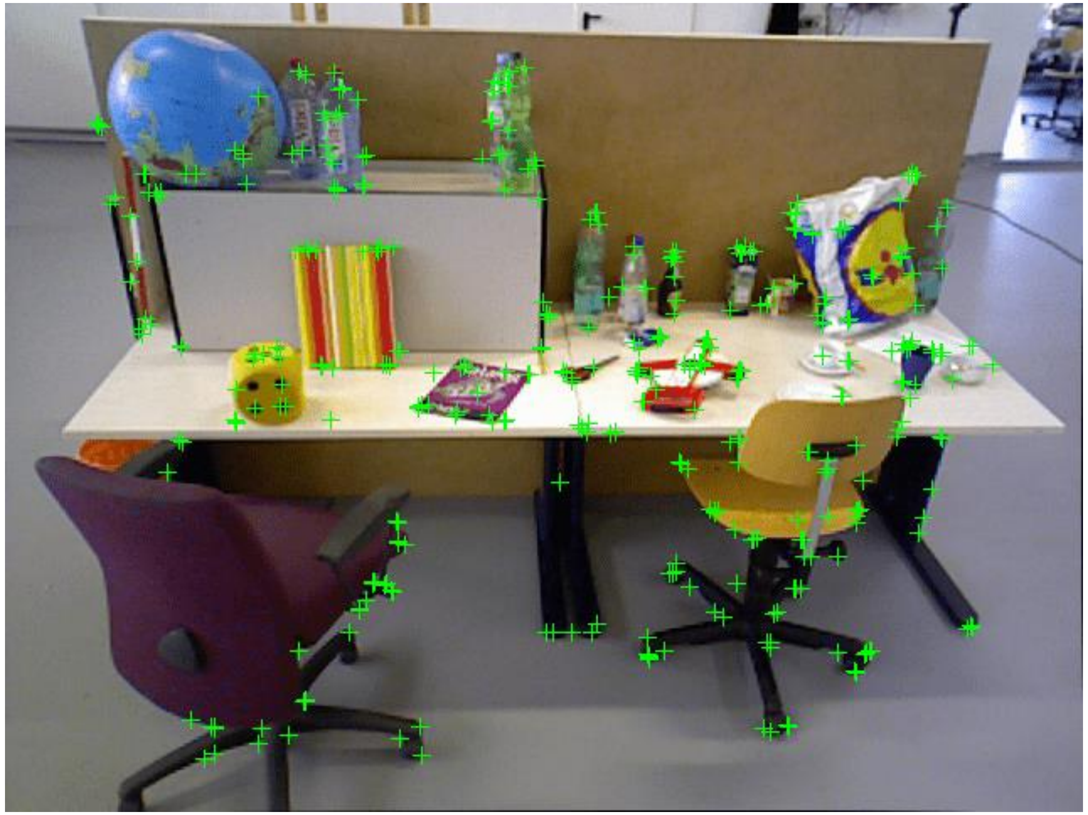
- Steps:
  - Feature detection
  - Stereo camera localisation
  - Feature matching
  - Point cloud
  - SLAM
  - Monocular SLAM



1) https://www.croptracker.com/blog/computer-vision-in-agriculture-part-1.html

Image feature tracking

- What to track: features
  - Detect changes in image **contrast**
- Different ways to describe the feature
  - Need to be able to find it with changes
  - Transfer from one image to another
- Different algorithms / descriptors
  - Orbs, SIFT, SURF, BRIEF



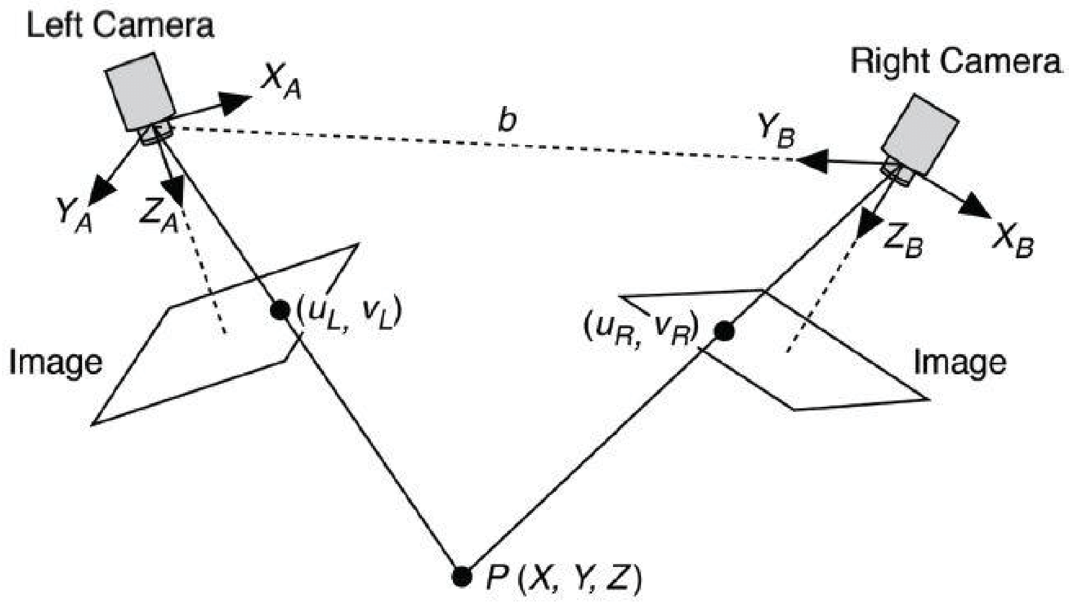
1) https://ch.mathworks.com/help/vision/ug/monocular-visual-simultaneous-localization-and-mapping.html

Stereo camera localisation

- How to calculate 3D space?
  - Use two images - Depth perception

- Practical example
  - Look at a far wall
  - Hold a finger in front of eyes
  - Alternate closing each eye
  - Finger jumps, wall does not

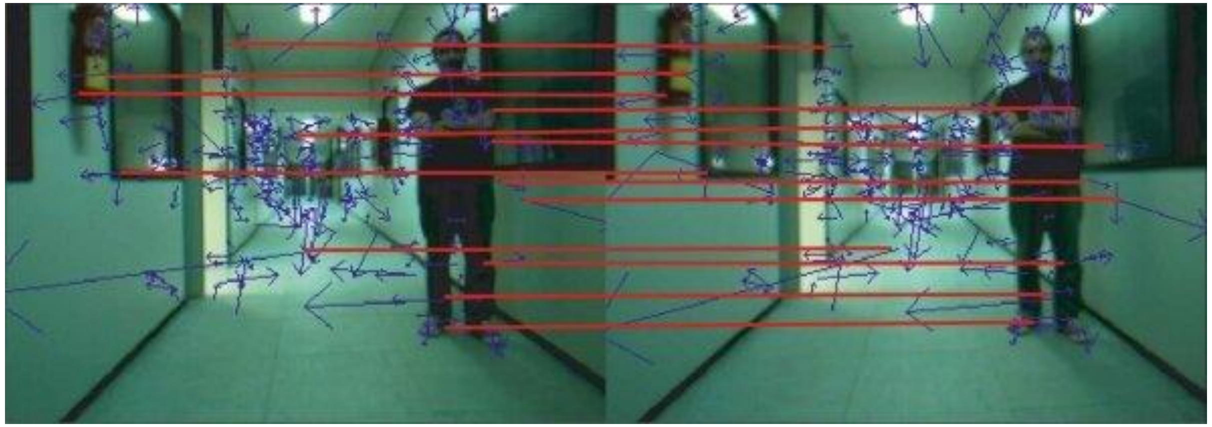
- *Stereo* camera localisation
  - Both see the same feature, need to compare!

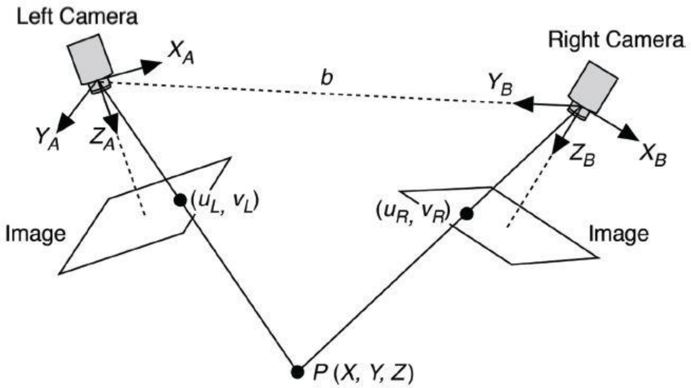


1) https://www.researchgate.net/publication/333665114_Towards_Low-Cost_Indoor_Localisation_Using_a_Multi-camera_System

Stereo camera localisation (2)

- Algorithm:
  - Both cameras detect features independently
  - Match features between images
  - Distances between cameras known
    - Triangulation to find position in 3D space





- Video feed from cameras:
  - *If most static features move closer, the camera must be moving towards the features!*

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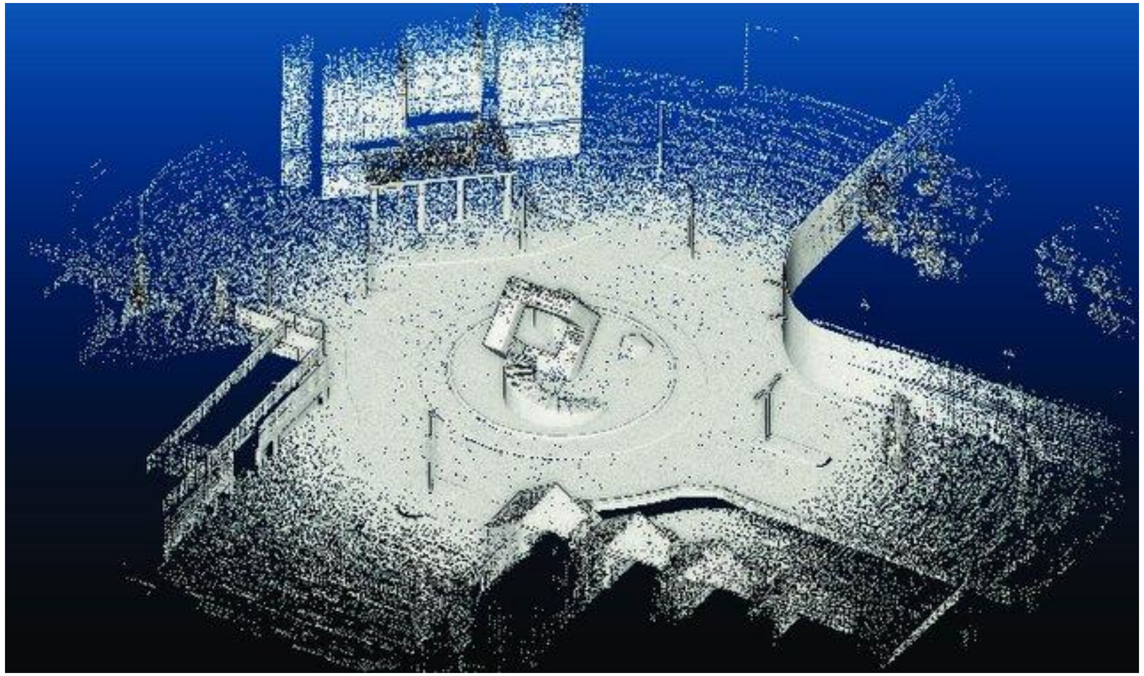
1) https://www.researchgate.net/publication/51873493_Visual_Odometry_Based_on_Structural_Matching_of_Local_Invariant_Features_Using_Stereo_Camera_Sensor/figures?lo=1
2) Generation of stereo images from the heterogeneous cameras

Stereo camera mapping (3)

- The features can be saved into memory
  - Then if feature is blocked, then can find it again from memory
- All features builds a *map* of the environments
- Map of points called a ***point cloud***



1) https://www.researchgate.net/publication/367982556_Building_Maps_Using_Monocular_Image-feeds_from_Windshield-mounted_Cameras_in_a_Simulator_Environment/figures?lo=1

Point cloud tracking of fruit

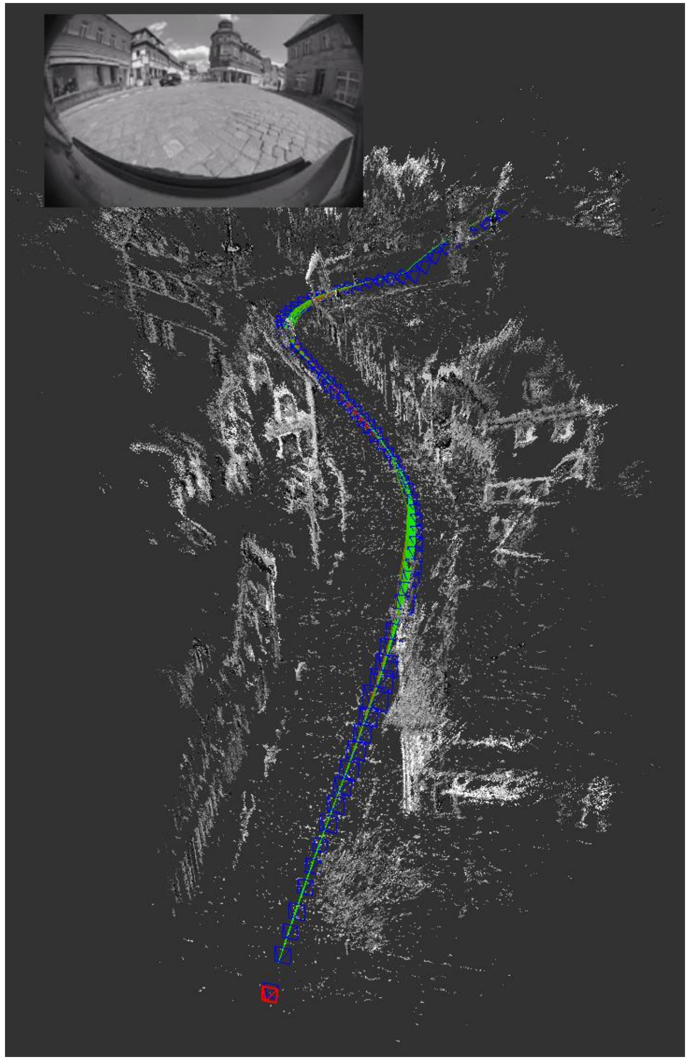
1) Riccardi A, Kelly S, Marks E, Magistri F, Guadagnino T, Behley J, Bennewitz M, Stachniss C. Fruit Tracking Over Time Using High-Precision Point Clouds. In2023 IEEE International Conference on Robotics and Automation (ICRA) 2023 May 29 (pp. 9630-9636). IEEE.

SLAM Introduction

- Algorithm called SLAM:
  - **S**imultaneous **L**ocalisation **A**nd **M**apping

- Both builds a map and localises the robot within it

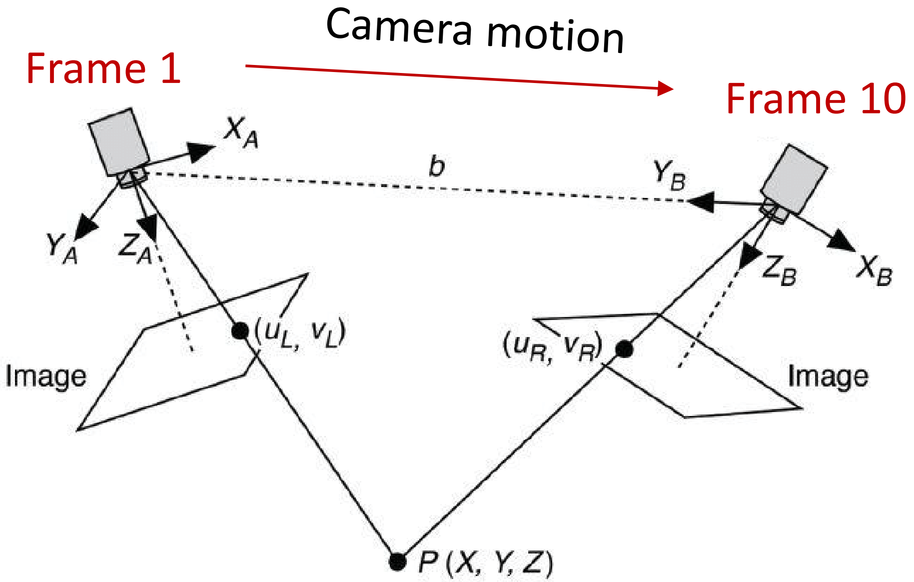
- Can return to previous places and recognise features



1) Sridevi M, Sugirtha T, Kiran BR, Yogamani S. Localization and Mapping for Autonomous Driving. InAutonomous Driving and Advanced Driver-Assistance Systems (ADAS) 2021 Dec 15 (pp. 411-436). CRC Press.

Monocular SLAM

- Monocular SLAM -> One camera
- As the camera moves, features are compared to previous images
  - Comparing to previous reference frames, it's like two different perspectives
  - Emulates two fields of view
- Example: close one eye and walk around
  - Can still estimate depth!



1) https://docs.opencv.org/4.x/d1/d89/tutorial_py_orb.html

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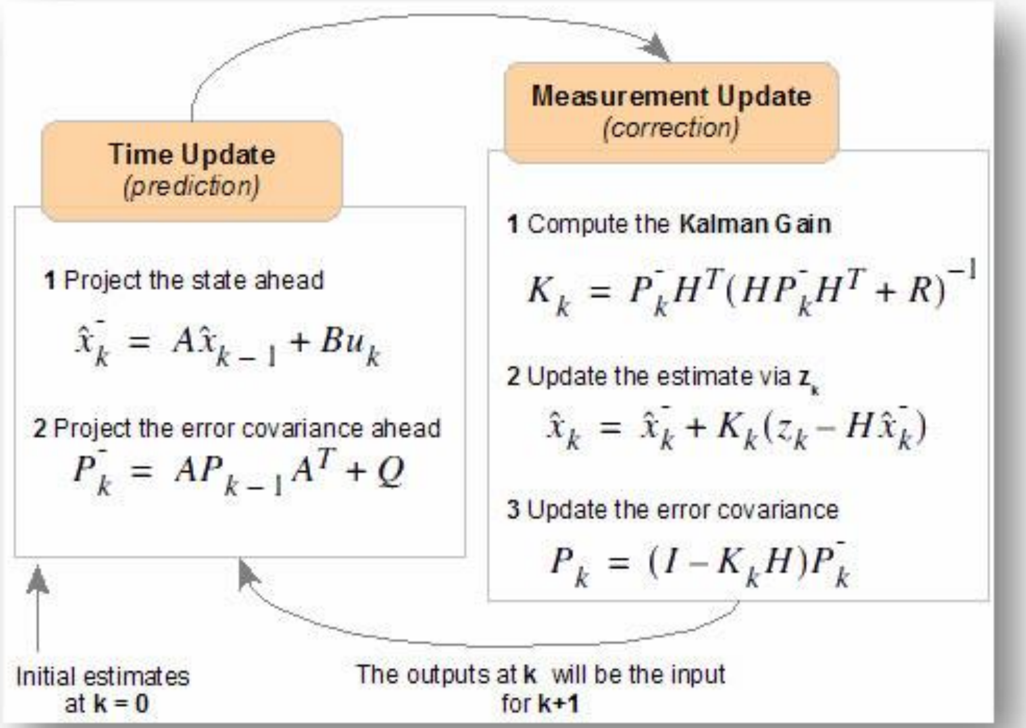
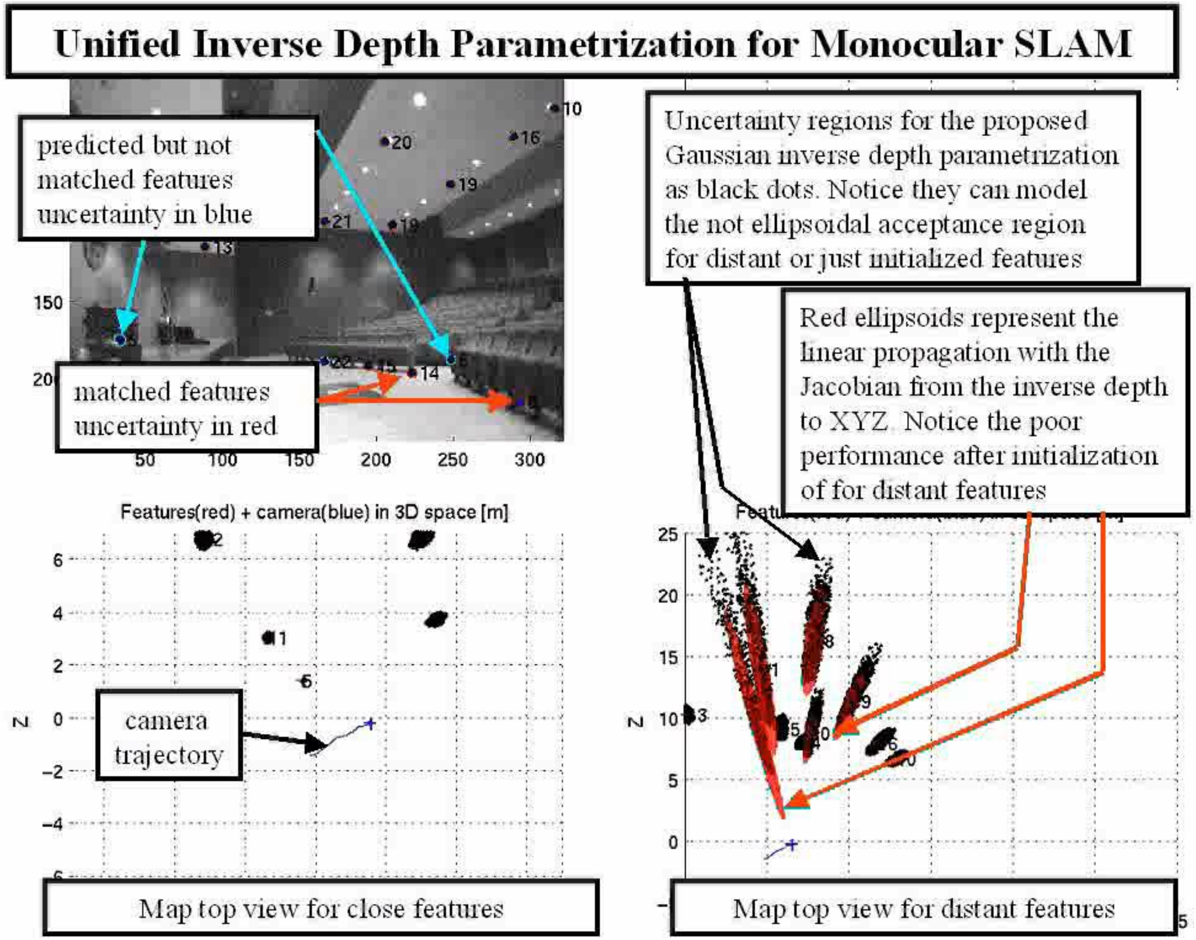
Monocular SLAM

- Probabilistic algorithm
  - Probability that features match
  - Probability of remembering seen locations
  - Variances of the distances of features
  - Probability that the camera has moved
- Two steps:
  - Predict the next state
    - E.g., camera motion from momentum
  - Correct the state from measurements
    - E.g., fix small corrections from features



1) http://vision.ia.ac.cn/Students/gzp/monocularslam.html

Monocular SLAM (2)



1) Montiel JM, Civera J, Davison AJ. Unified Inverse Depth Parametrization for Monocular SLAM. InRobotics: science and systems 2006 Aug 16 (Vol. 3, pp. 1-8).

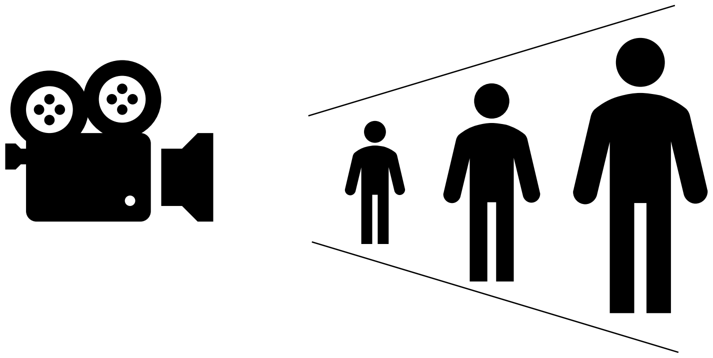
Monocular SLAM (3)

- Major catch:
  - Don’t actually know the scale!

1) https://www.scmp.com/culture/arts-entertainment/article/2137964/hong-kong-exhibition-street-art-features-joshua-smith

Monocular SLAM (3)

- Major catch:
  - Don't actually know the scale!

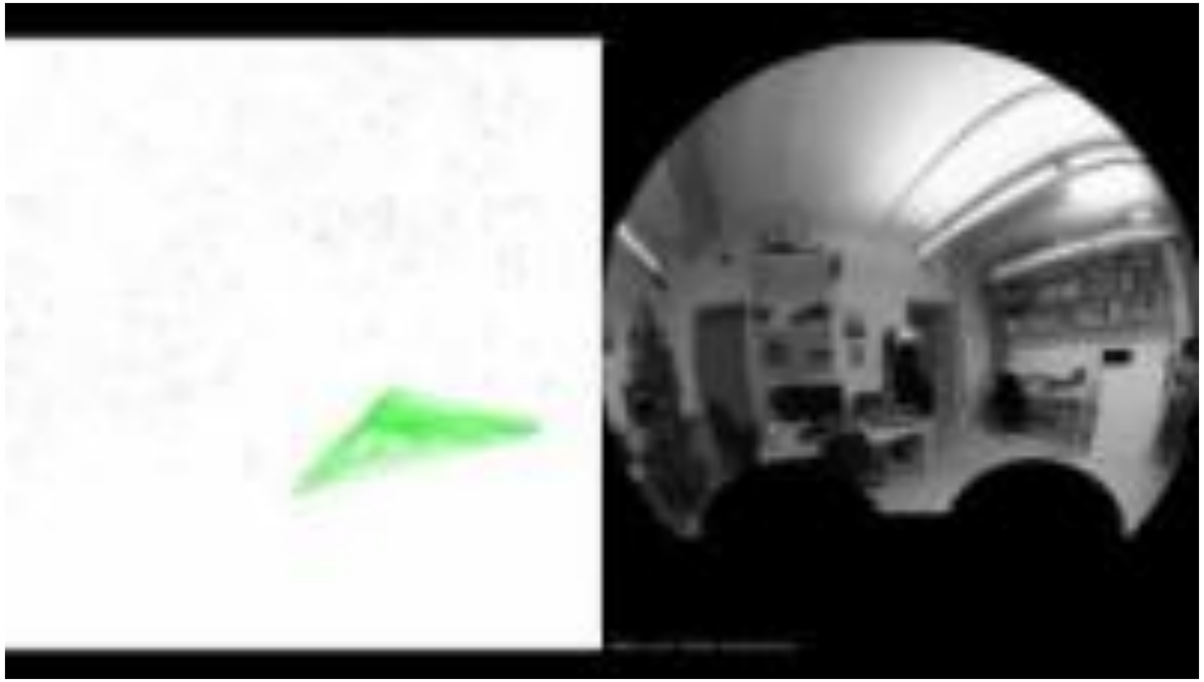


All three appear the same to the camera

- *Need external reference to get distance*

1) https://www.scmp.com/culture/arts-entertainment/article/2137964/hong-kong-exhibition-street-art-features-joshua-smith

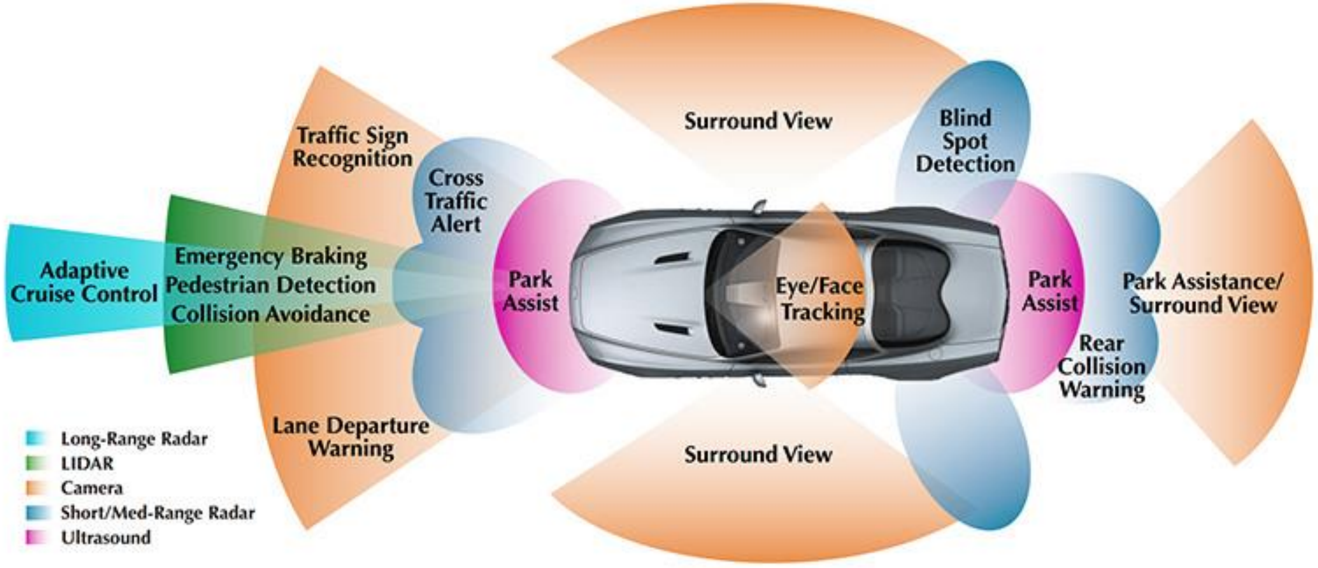
Monocular SLAM - Example



1) Come on and SLAM: Analysis of the Impact of Field of View on Wide-Angle Cameras in SLAM, 2018

SLAM – Sensor fusion

- Full SLAM
  - Integrates multiple measurements together
- Internal measurements
  - High fidelity
- External measurements
  - Distance and coordination
  - Lidar



1) https://ecotron.ai/blog/introduction-to-autonomous-driving-sensors/

Callback – underground SLAM

1) https://en.wikipedia.org/wiki/Lidar

Learning goals

- Understand how robots are able to locate themselves in the environment
  - Absolute vs relative positioning
- Discuss how GNSS systems function
  - Satellite, RTK
- Understand basic sensors used for localisation
  - Internal, external sensors
- Explain the basics of computer-vision based localisation
  - Feature tracking, Stereo and monocular SLAM