Drones Demystified!

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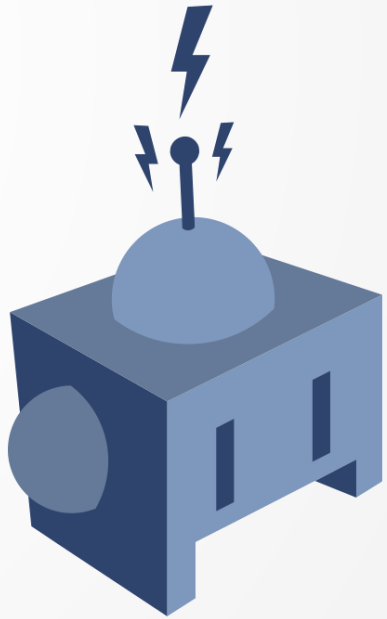
Drones Demystified!

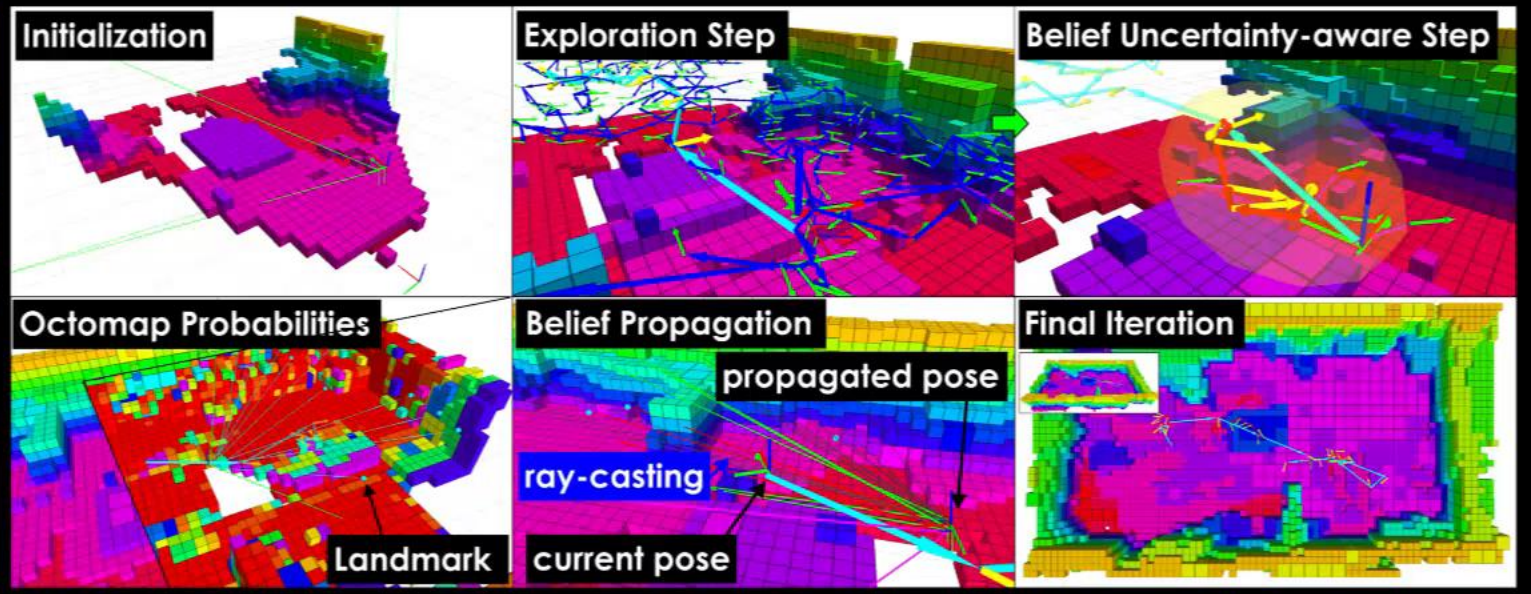
Topic: The Inertial Measurement Unit

Where am I in the environment?



Uncertainty-aware Receding Horizon Exploration and Mapping using Aerial Robots

Christos Papachristos, Shehryar Khattak, Kostas Alexis



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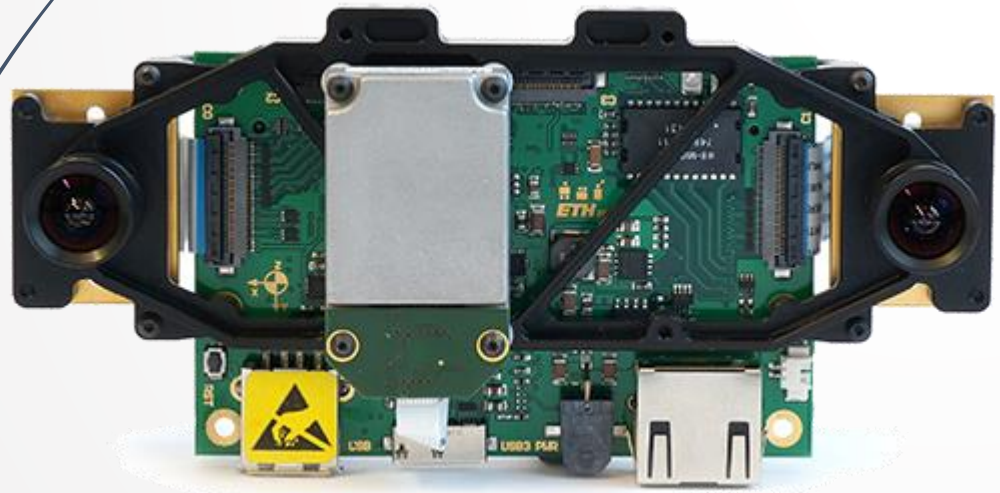
Navigation Sensors

- Providing the capacity to estimate the **state** of the aerial robot
  - **Self-Localize and estimate its pose in the environment**
  - **Often this requires to also derive the map of the environment**
  - **In some cases also rely in external systems (e.g. GPS), while a lot of work is undergoing into making aerial robots completely autonomous.**

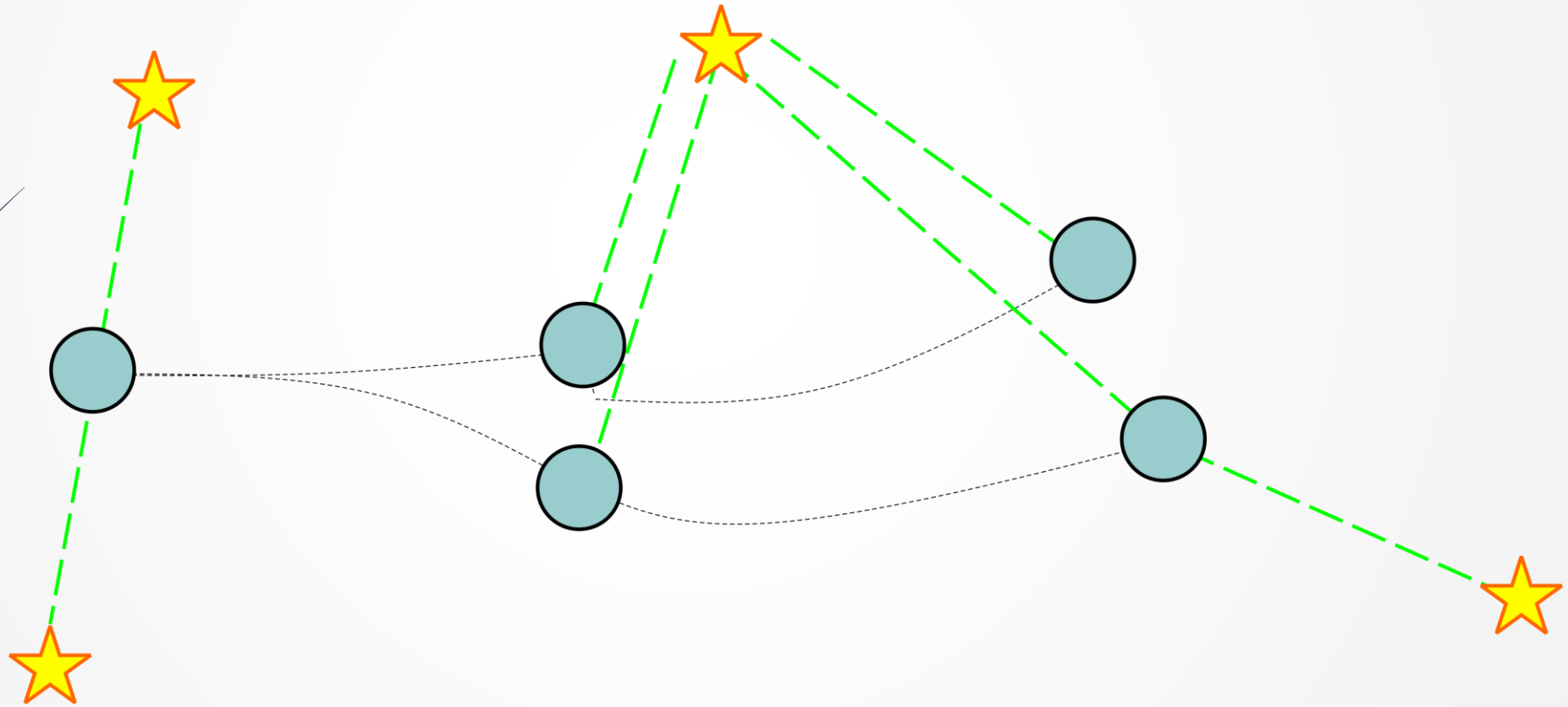


Navigation Sensors

- A robot has to be able to localize itself and map its environment.
- This process is typically a combined problem – a robot has to simultaneously localize itself and map its surroundings. Localization depends on mapping and viceversa: a combined, chicken-and-egg, problem.
  - Localization: estimating the robot's location
  - Mapping: building a map
  - Simultaneous Localization And Mapping (SLAM): building a map and localizing the robot together

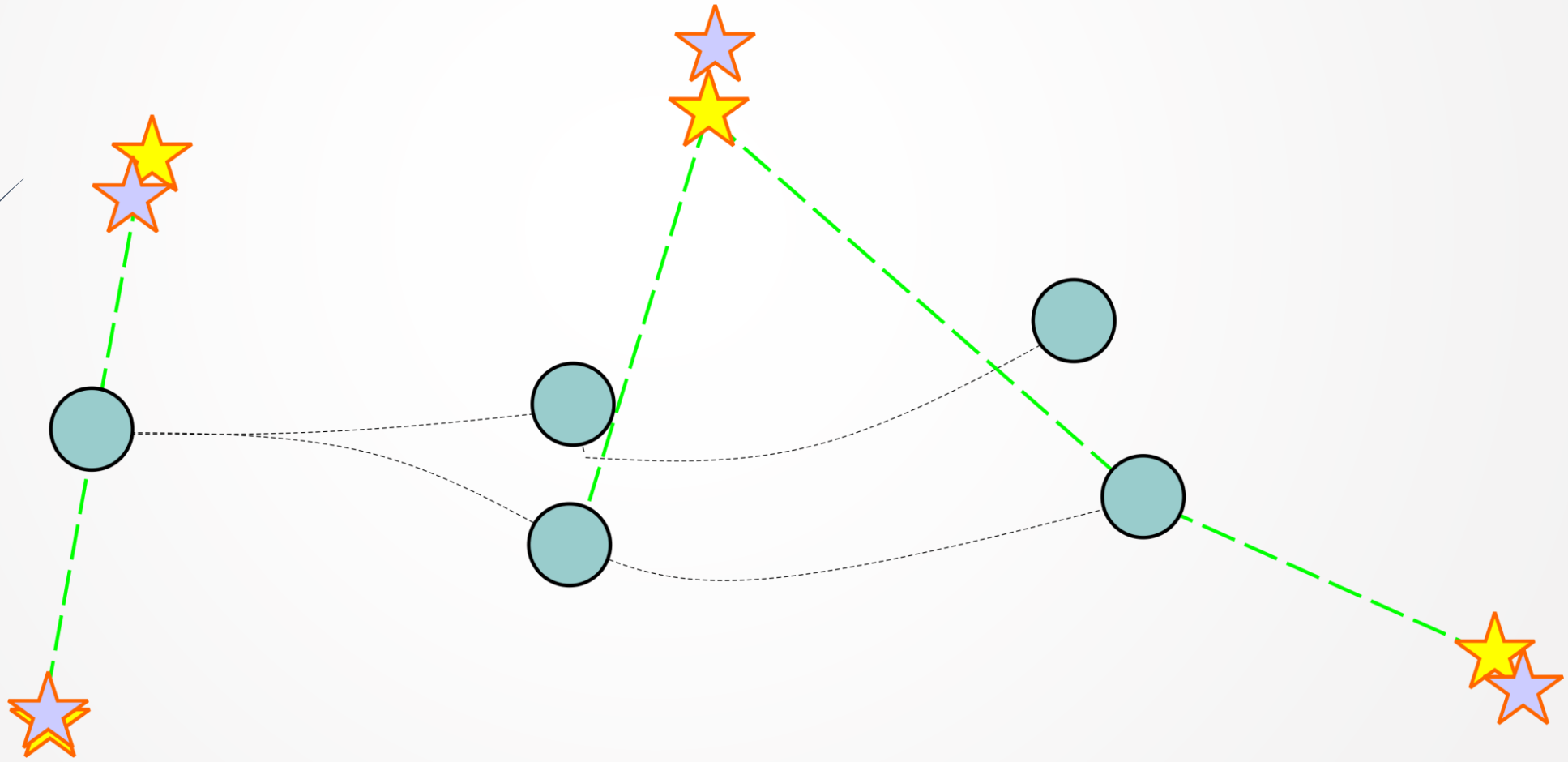
Navigation Sensors

- **Localization example:** Estimate the robot's poses given known landmarks



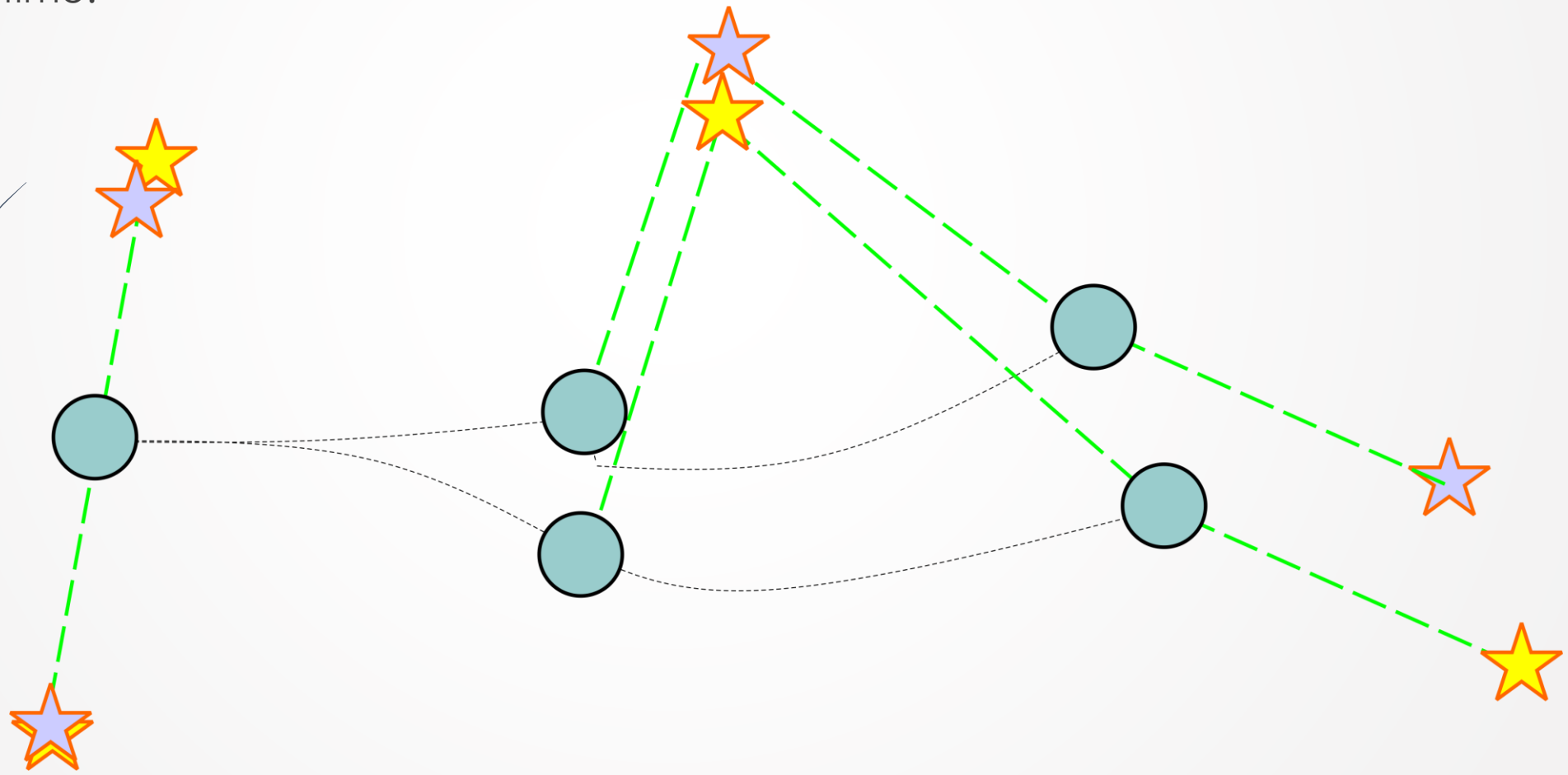
Navigation Sensors

- **Mapping example:** Estimate the robot's poses given known landmarks



Navigation Sensors

- **SLAM example:** Estimate the robot's poses and the landmarks at the same time.



Course Module Topics

- Inertial Sensors and GPS
- Camera and LiDAR sensors

Sensing technology

- State Estimation theory and the Kalman Filter
- SLAM

Estimation theory

- A case study: Visual-Inertial SLAM

State of the art methods

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State of the art methods

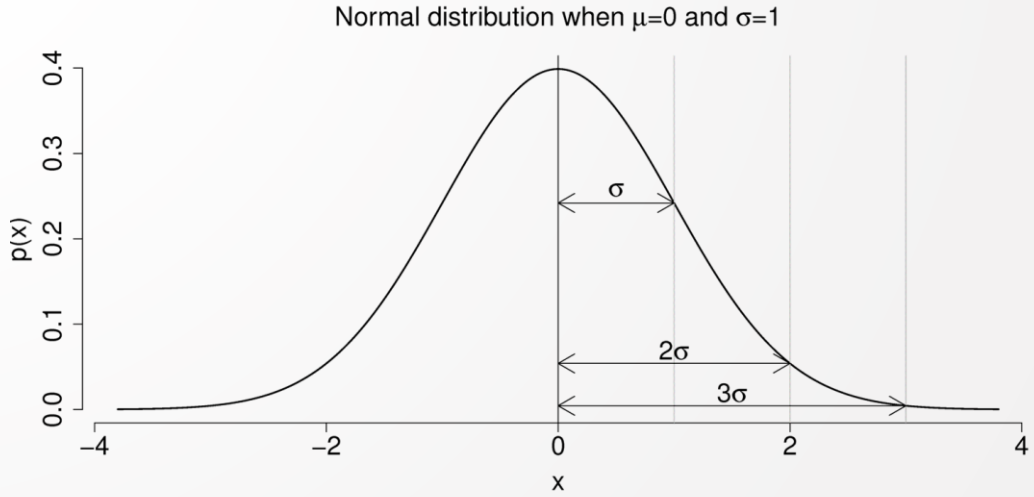
Classification of Sensors

- *What:*
  - **Proprioceptive sensors**
    - Measure values internally to the robot.
      - Angular rate, heading.
  - **Exteroceptive sensors**
    - Information from the robot environment
      - Distances to objects, extraction of features from the environment.

- *How:*
  - **Passive Sensors**
    - Measure energy coming from a signal of the environment – very much influenced from the environment.
  - **Active Sensors**
    - Emit their proper energy and measure reaction.
    - Better performance, but some influence on the environment.
    - Not always easily applicable concept.

Uncertainty Representation

- **Sensing is always related to uncertainties**
  - How can uncertainty be represented or quantified?
  - How do they propagate – uncertainty of a function of uncertain values?
- **Systematic errors**
  - They are caused by factors or processes that can in theory be modeled and, thus, calibrated, (for example the misalignment of a 3-axes accelerometer)
- **Random errors**
  - They cannot be predicted using a sophisticated model but can only be described in probabilistic terms



Expected value of a Random Variable

- **Discrete case:** $$E[X] = \sum_i x_i P(x_i)$$

- **Continuous case:** $$E[X] = \int x P(X = x) dx$$

- The expected value is the weighted average of all values a random variable can take on.
- Expectation is a linear operator:

$$E[aX + b] = aE[X] + b$$

Covariance of a Random Variable

- Measures the **square expected deviation from the mean**:

$$Cov[X] = E[X - E[X]]^2 = E[X^2] - E[X]^2$$

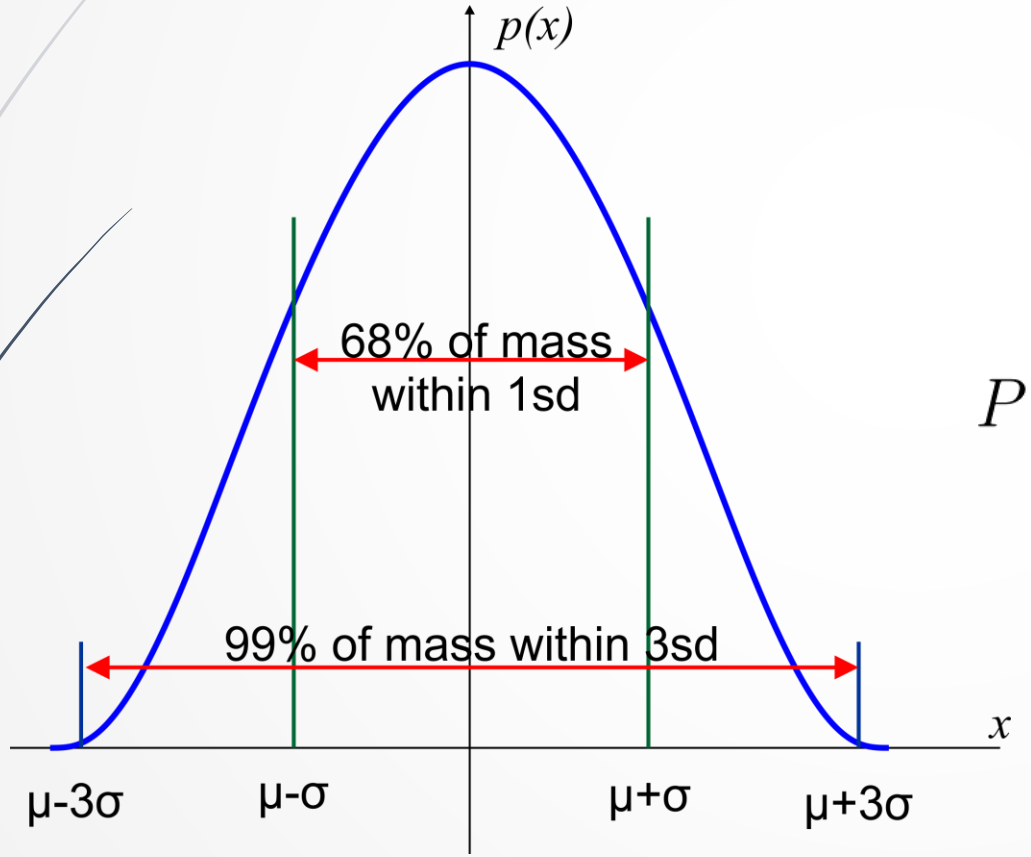
Estimation from Data

- Observations: $\mathbf{x}_1, \mathbf{x}_2, \ldots, \mathbf{x}_n \in \mathcal{R}^d$
- Sample Mean: $$\mu = \frac{1}{n} \sum_i \mathbf{x}_i$$
- Sample Covariance:

$$\Sigma = \frac{1}{n-1} \sum_i (\mathbf{x}_i - \mu)(\mathbf{x}_i - \mu)$$

Statistical sensor reading representation

- Univariate distribution



$$X \sim \mathcal{N}(\mu, \sigma^2)$$

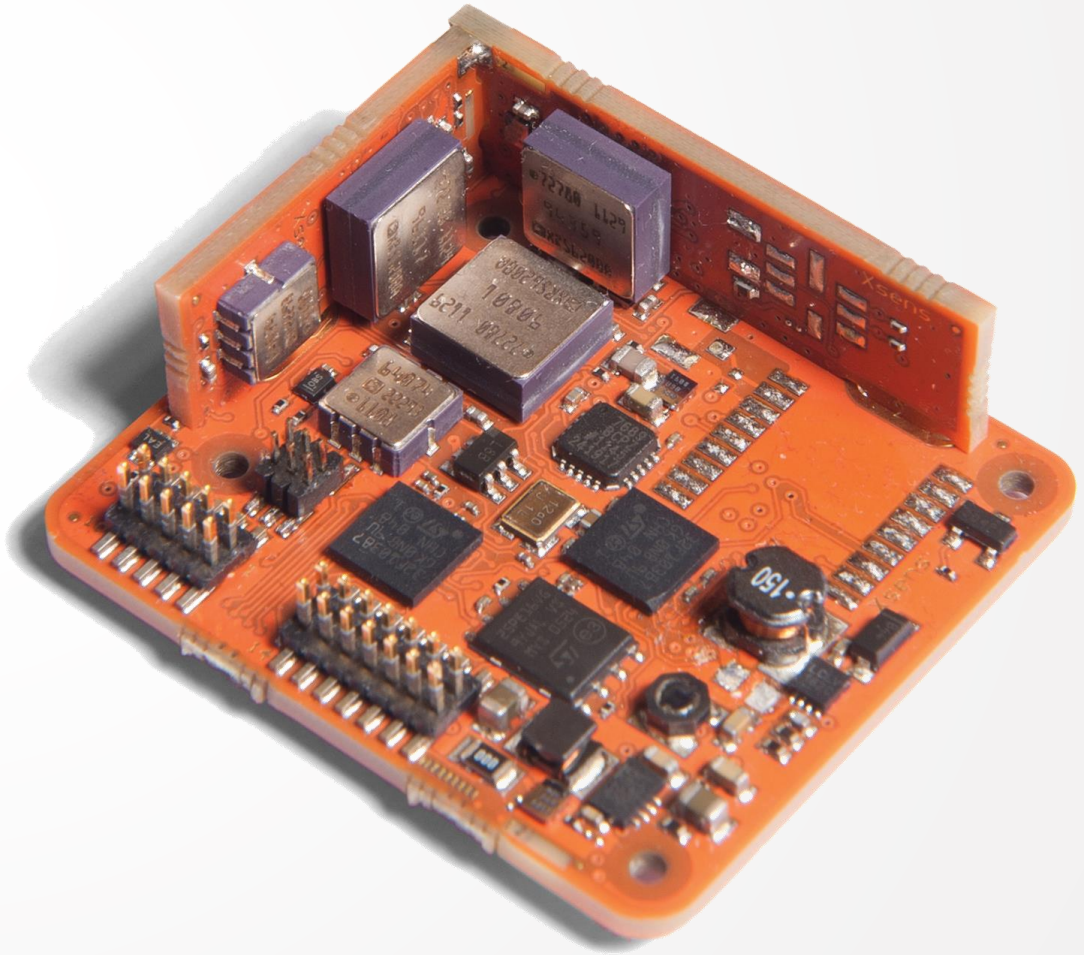
mean

Variance (squared standard deviation)

$$P(X = x) = \frac{1}{\sqrt{2\pi}\sigma} \exp(-\frac{1}{2}\frac{(x-\mu)^2}{\sigma^2})$$

Typical Navigation Sensors

- The following sensors are commonly used for the navigation of aerial robots:
  - **Inertial Sensors:**
    - Accelerometers
    - Gyroscopes
  - **Magnetometers (digital compass)**
  - **Pressure Sensors**
    - Barometric pressure for altitude sensing
    - Airspeed measurements
  - **GPS**
  - **Camera based systems**
  - **Time-of-Flight sensors**



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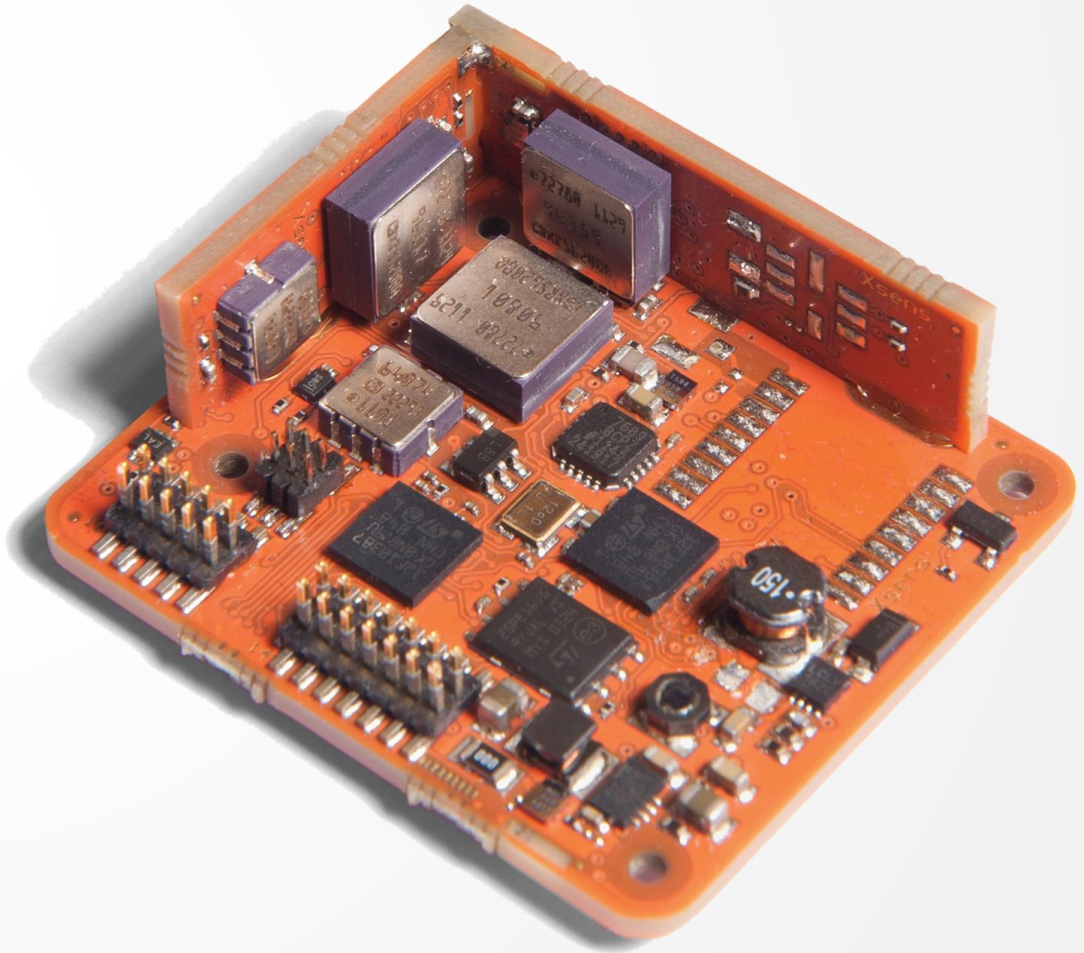
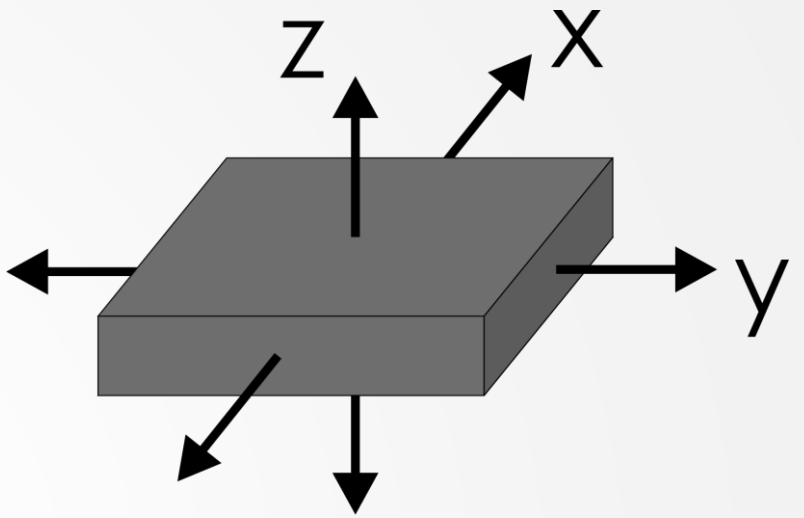
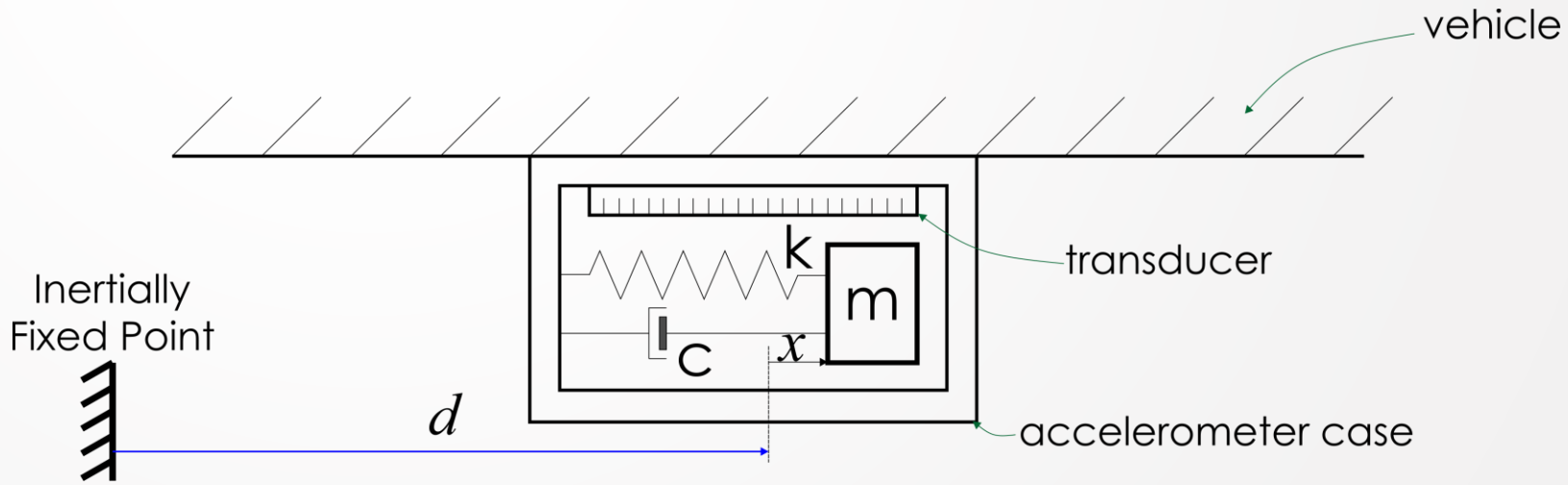
Topic of this presentation



Accelerometer

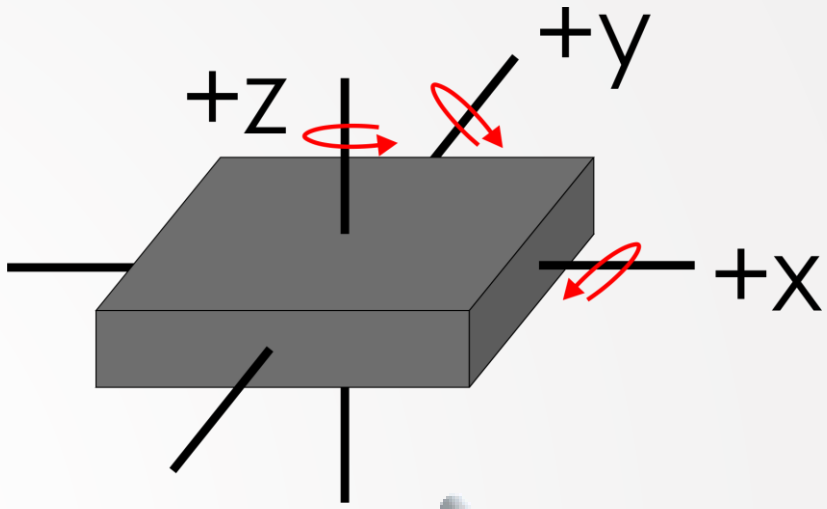


- Accelerometers are devices that **measure proper acceleration** ("g-force"). Proper acceleration is not the same as coordinate acceleration (rate of change of velocity). For example, an accelerometer at rest on the surface of the Earth will measure an acceleration g= 9.81 m/s^2 straight upwards.
- Accelerometers are electromechanical devices that are able of measuring static and/or dynamic forces of acceleration. Static forces include gravity, while dynamic forces can include vibrations and movement. Accelerometers can measure acceleration on 1, 2 or 3 axes.



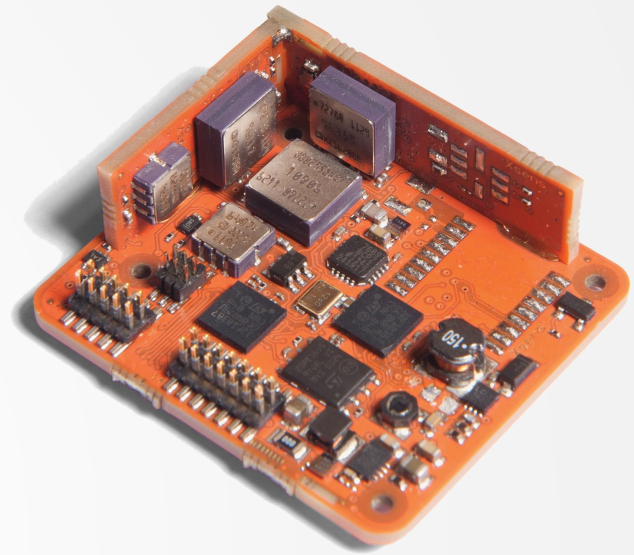
Gyroscope

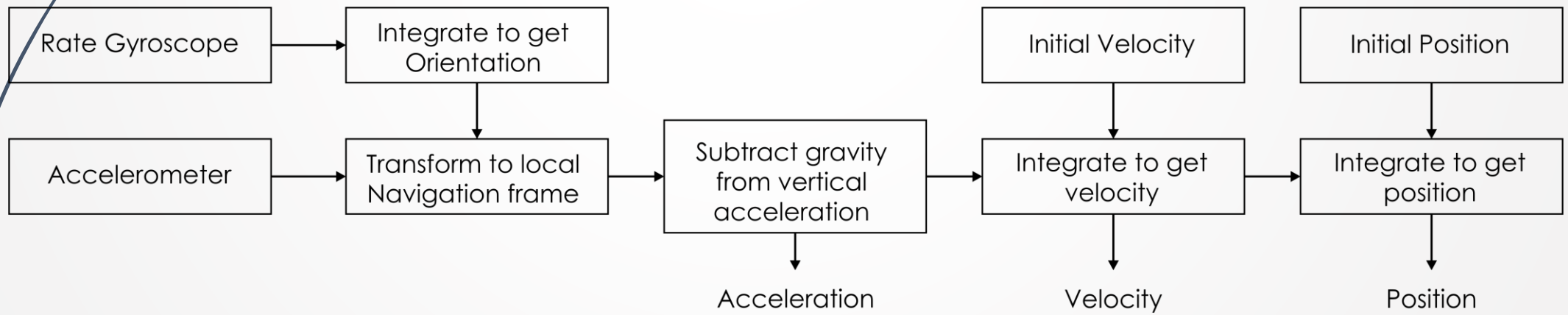
- **A gyroscope is - conceptually - a spinning wheel in which the axis of rotation is free to assume any possible orientation.** When rotating, the orientation of this axis remains unaffected by tilting or rotation of the mounting, **according to the conservation of angular momentum**. Due to this principle, a gyroscope can lead to the measurement of orientation and its rate of change. The word comes from the Greek "γύρος" and σκοπεύω which mean "circle" and "to look" correspondingly.
- Nowadays, we are mostly using gyroscopes that are based on different operating principles. In aviation we especially focus on MEMS gyroscopes or solid-state ring lasers, and fibre optic gyroscopes. In small-scale aerial robotics, we mostly care for MEMS gyroscopes.



Simplified IMU

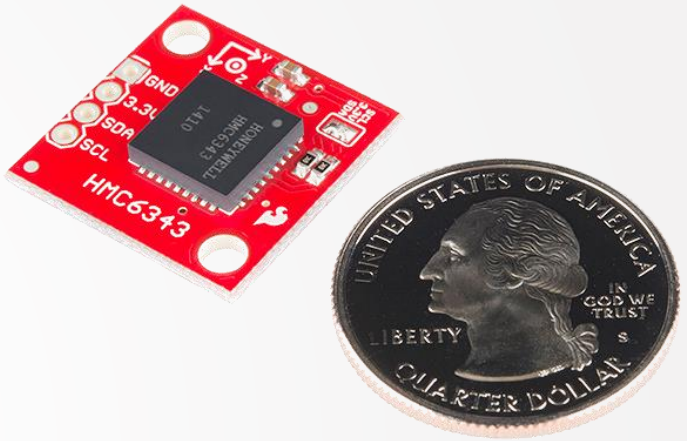
- It uses gyroscopes and accelerometers to estimate the relative pose (position and orientation), velocity and acceleration of a moving vehicle with respect to an inertial frame.
- In order to estimate the motion, the gravity vector must be subtracted and the initial velocity has to be known.
- After long periods of operation, drifts occur: need external reference to cancel it.

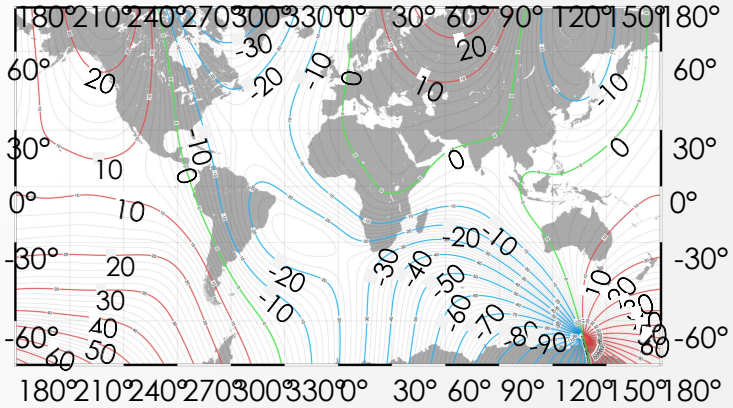




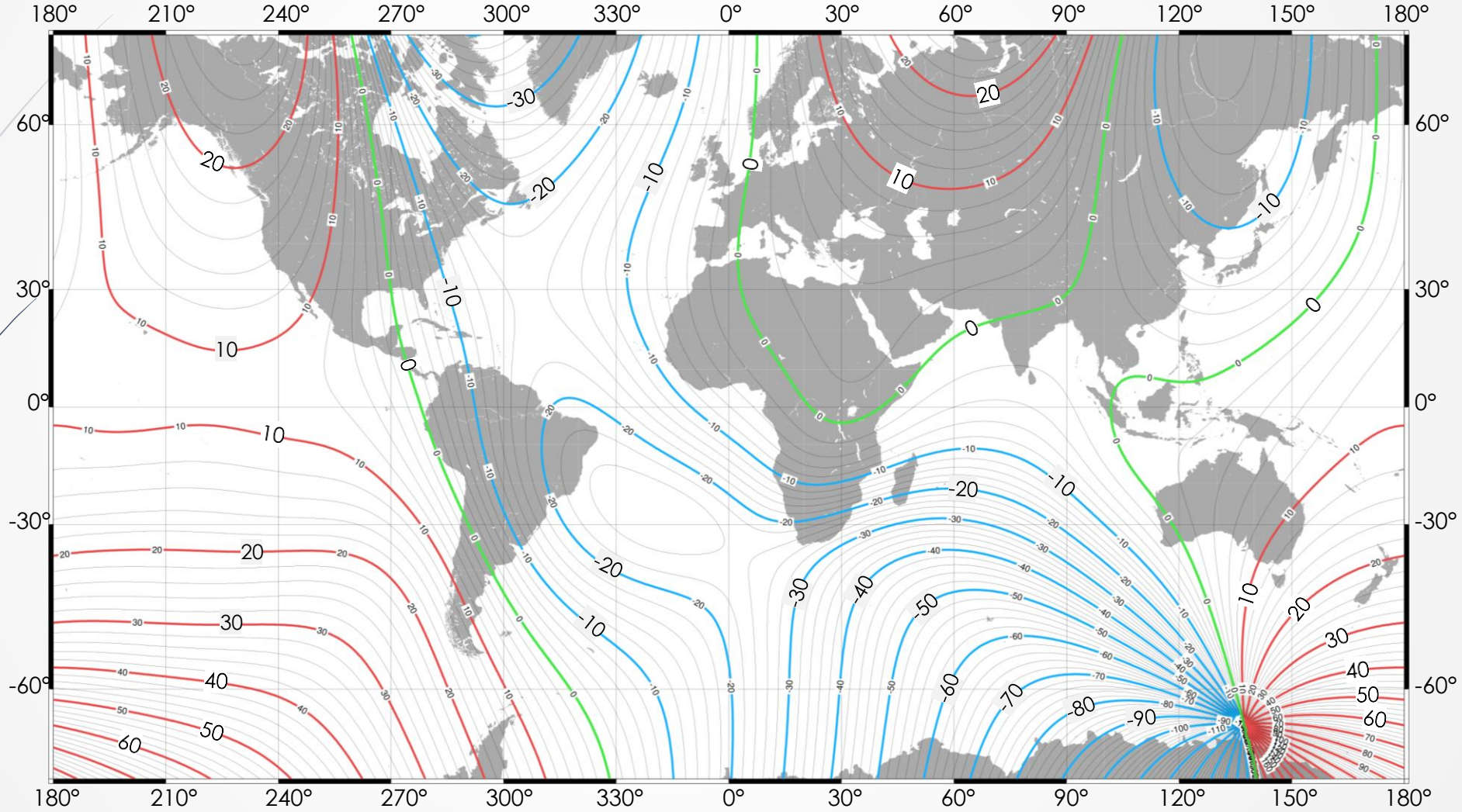
Magnetometer

- A magnetometer is a type of sensor that measures the strength and direction of the local magnetic field. The magnetic field measured will be a combination of both the earth's magnetic field and any magnetic field created by nearby objects. The magnetic field is measured in the sensor reference frame.
- The earth's magnetic field is a self sustaining magnetic field that resembles a magnetic dipole with one end near the Earth's geographic North Pole and the other near the earth's geographic South Pole. The strength of this magnetic field varies across the Earth with strengths as low as 0.3 Gauss in South America to over 0.6 Gauss in northern Canada.





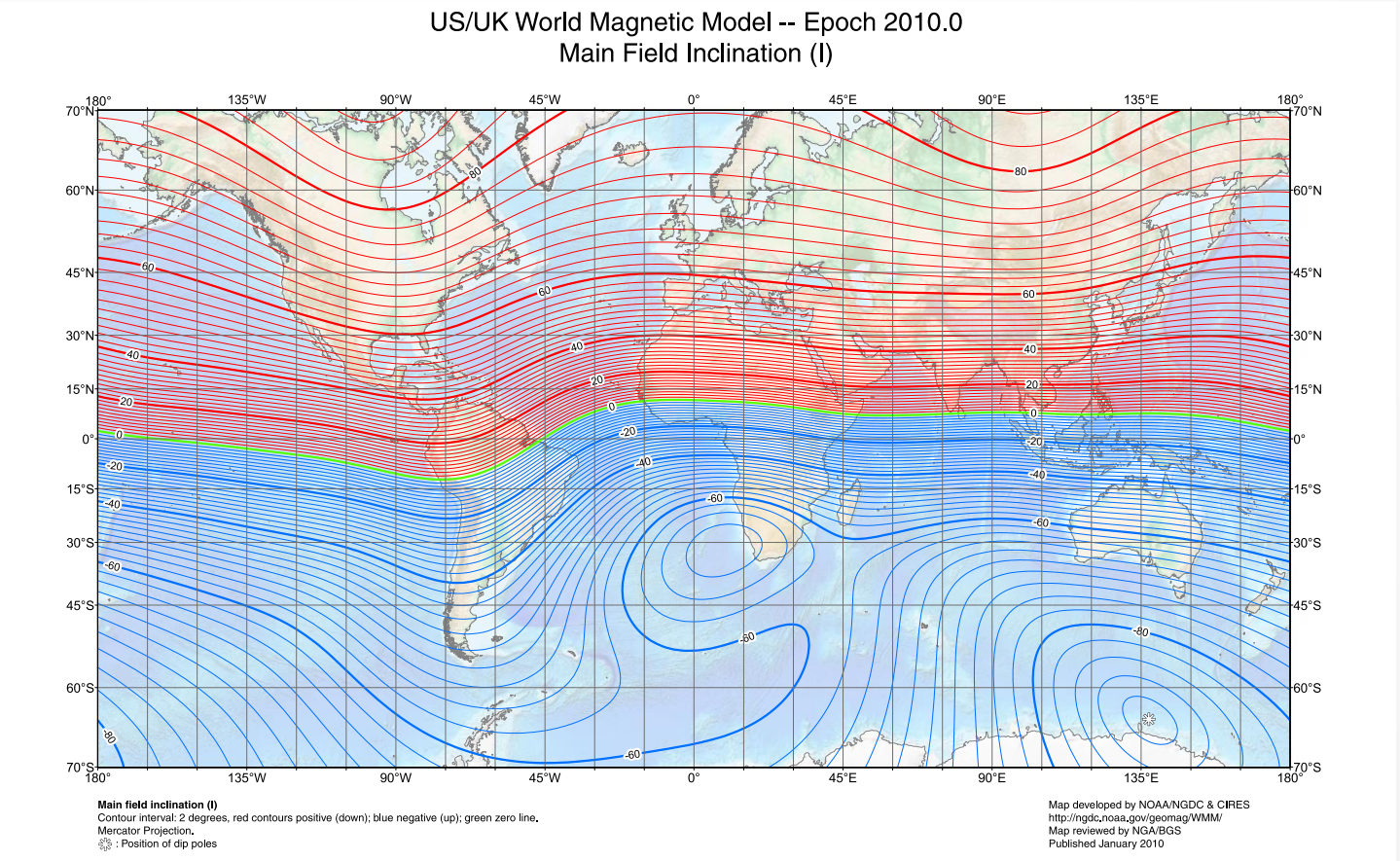
Magnetic Declination Variation



World Magnetic Model, National Geophysical Data Center

Magnetic Inclination

Magnetic dip or magnetic inclination is the angle made by a compass needle with the horizontal at any point on the Earth's surface. Positive values of inclination indicate that the field is pointing downward, into the Earth, at the point of measurement.



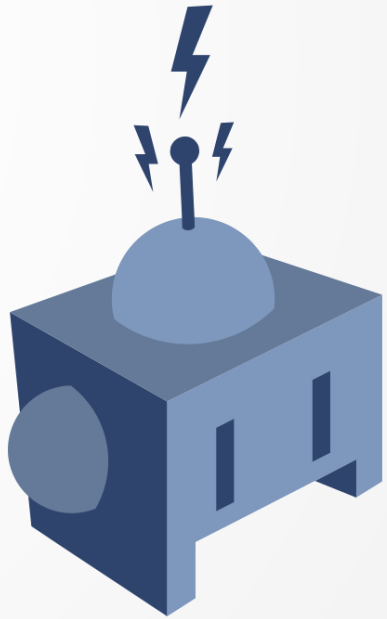
Pressure Measurements

- A pressure sensor measures pressure, typically of gases or liquids. Pressure is an expression of the force required to stop a fluid from expanding, and is usually stated in terms of force per unit area. A pressure sensor usually acts as a transducer; it generates a signal as a function of the pressure imposed.

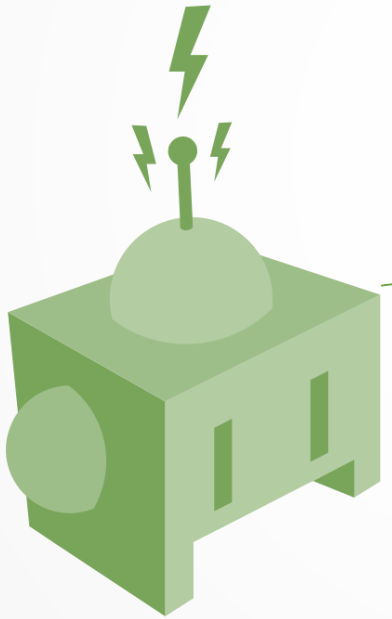
- **Pressure sensing:**
  - This is where the measurement of interest is pressure, expressed as a force per unit area. This is useful in weather instrumentation, aircraft, automobiles, and any other machinery that has pressure functionality implemented.

- **Altitude sensing:**
  - This is useful in aircraft, rockets, satellites, weather balloons, and many other applications. All these applications make use of the relationship between changes in pressure relative to the altitude.

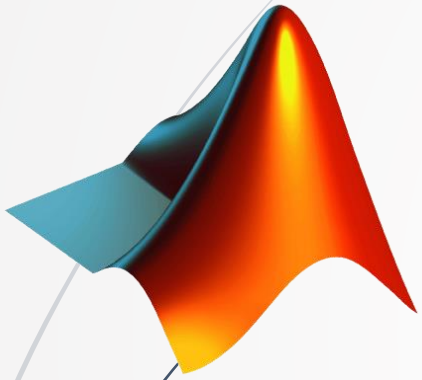
How do I fuse all the sensors to get attitude?



Refer to the State Estimation lecture



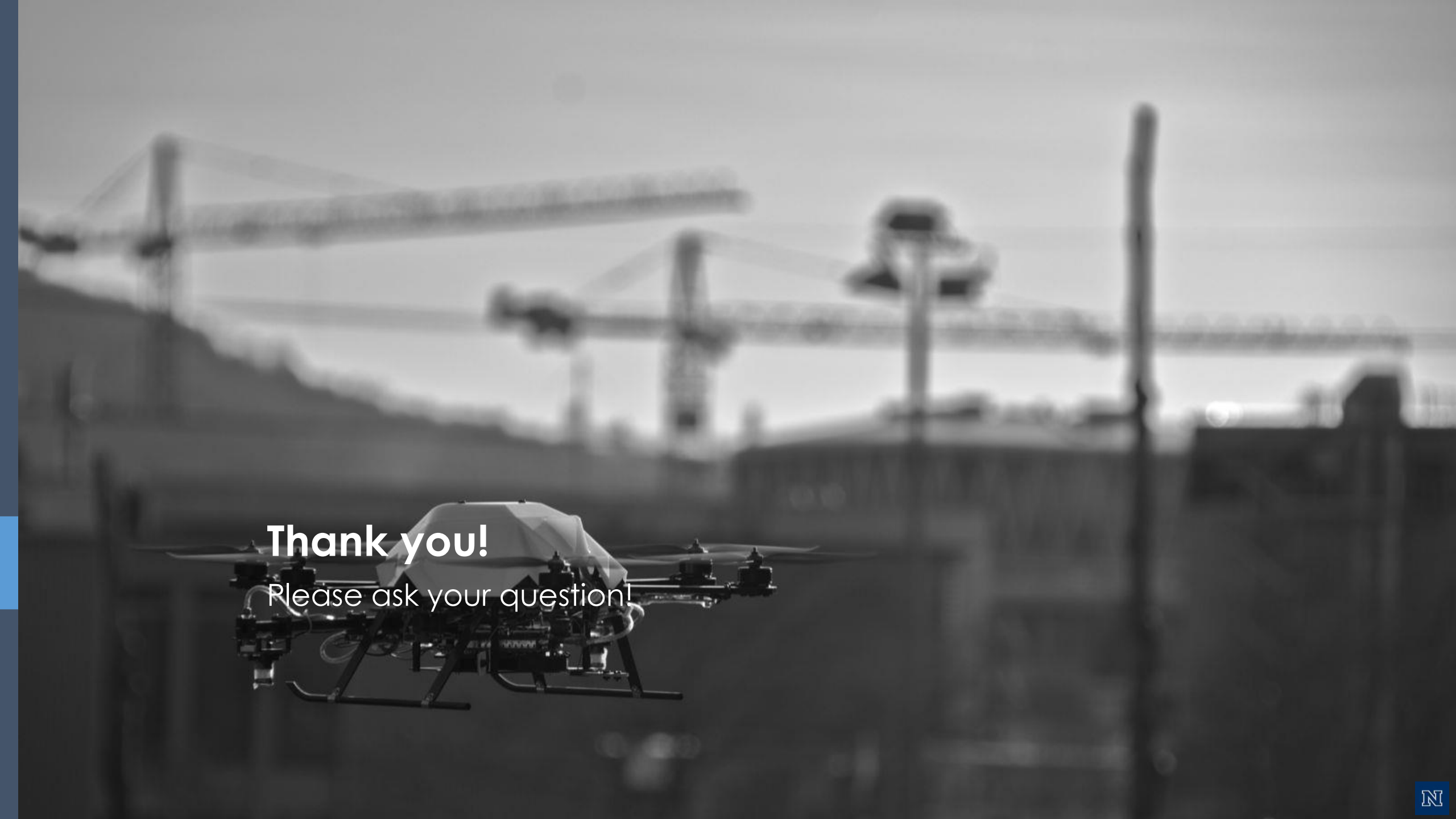
Code Example



- State Estimation examples
  - https://github.com/unr-arl/drones_demystified/tree/master/matlab/state-estimation
- ROSBAG with IMU Data
  - https://github.com/unr-arl/drones_demystified/tree/master/matlab/state-estimation

Find out more

- http://www.autonomousrobotslab.com/inertial-sensors.html
- http://px4.io/
- http://www.sensorwiki.org/
- http://www.autonomousrobotslab.com/literature-and-links.html



Thank you!

Please ask your question!