Autonomous Navigation for Flying Robots

Lecture 3.2:
Sensors

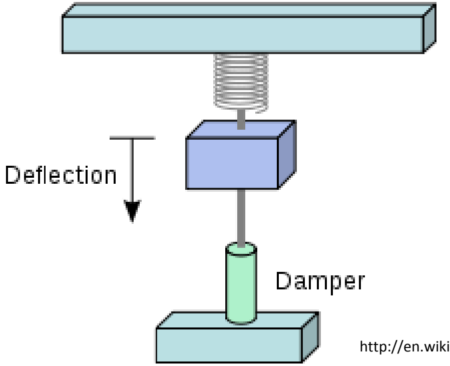
Jürgen Sturm
Technische Universität München

Sensors

- IMUs (inertial measurement units)
  - Accelerometers
  - Gyroscopes
- Range sensors (sonar)
- GPS
- Cameras

Accelerometers

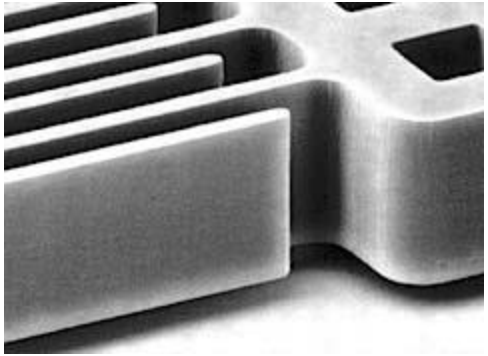
- Measures all external forces acting upon them (including gravity)
- Acts like a spring-damper system
- To obtain inertial acceleration (due to motion alone), gravity must be subtracted



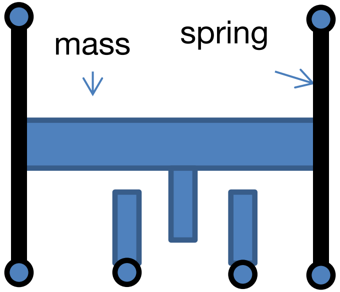
http://en.wikipedia.org/wiki/File:Pendular_accel.svg

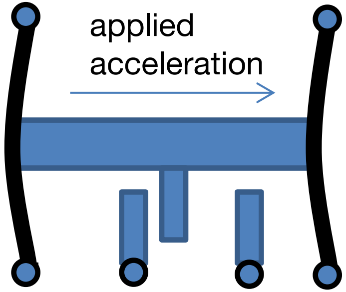
MEMS Accelerometers

- Micro Electro-Mechanical Systems (MEMS)
- Spring-like structure with a proof mass
- Damping results from residual gas
- Implementations: capacitive, piezoelectric, …



Bernstein, J., An Overview of MEMS Inertial Sensing Technology, Sensors, Feb. 2003.





Gyroscopes

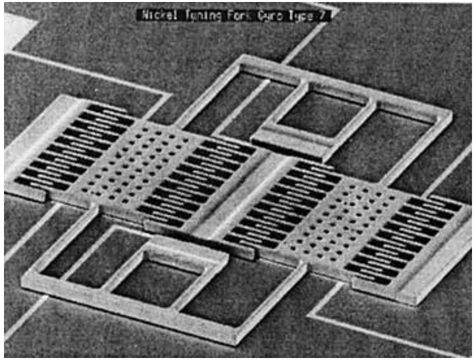
- Measures orientation (standard gyro) or angular velocity (rate gyro, needs integration for angle)
- Spinning wheel mounted in a gimbal device (can move freely in 3 dimensions)
- Wheel keeps orientation due to angular momentum

http://en.wikipedia.org/wiki/File:Gyroscope_operation.gif

http://en.wikipedia.org/wiki/File:Foucault%27s_gyroscope.jpg

MEMS Gyroscopes

- Vibrating structure gyroscope (MEMS)
  - Based on Coriolis effect
  - “Vibration keeps its direction under rotation”
  - Implementations: Tuning fork, vibrating wheels, …



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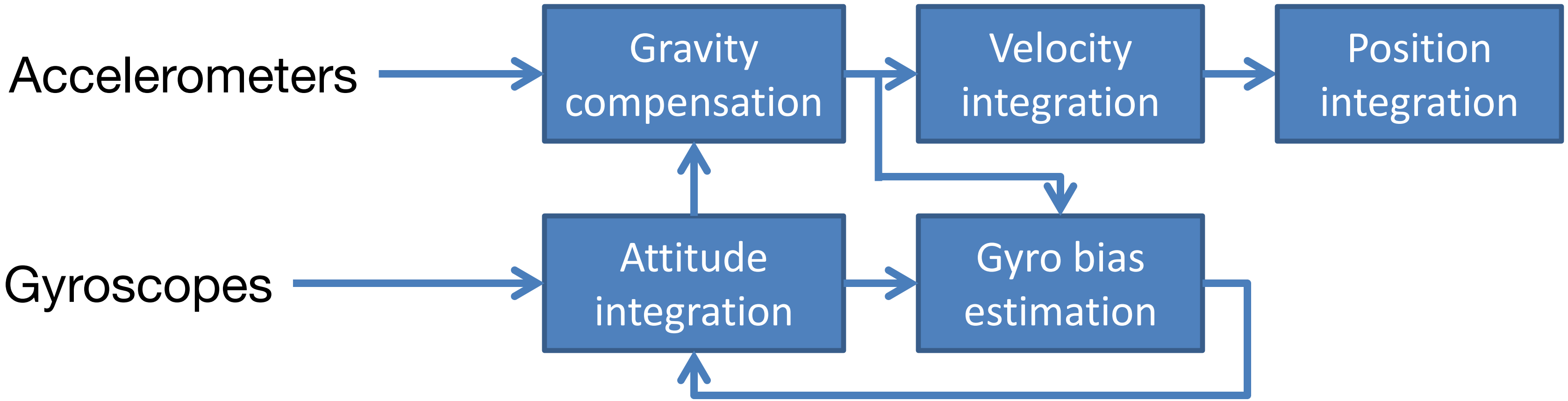
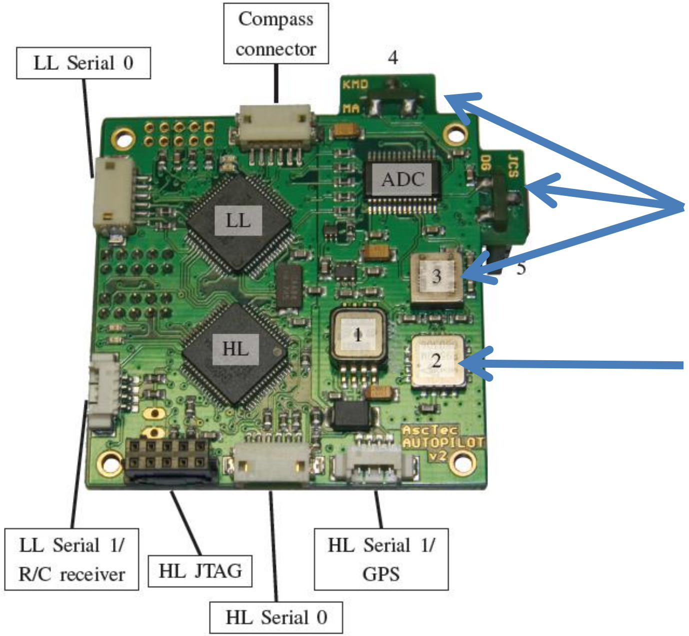
Inertial Measurement Units (IMUs)

- 3-axes MEMS gyroscope
  - Provides angular velocity
  - Integrate for angular position
  - Problem: Drifts slowly over time (e.g., 1deg/hour), called the bias
- 3-axes MEMS accelerometer
  - Provides accelerations (including gravity)

IMU Strapdown Algorithm



Example: AscTec Autopilot Board



1: pressure sensor
2: acceleration sensor
3: yaw gyro
4: nick gyro
5: roll gyro

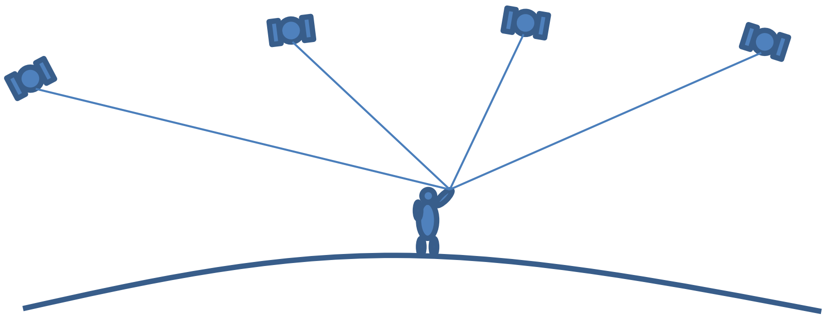
Gyroscopes (3x single axis)

Accelerometer (3-axes)

http://www.asctec.de/downloads/manuals/AscTec-Autopilot-Manual-v10.pdf

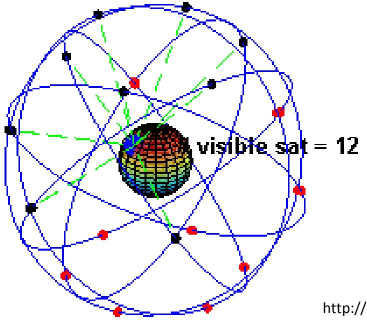
GPS

- Every satellite transmits its position and time
- Receiver measures time difference of satellite signals
- Calculate position by intersecting distances (pseudoranges)



GPS

- 24+ satellites, 12 hour orbit, 20.190 km height
- 6 orbital planes, 4+ satellites per orbit, 60deg distance
- Satellite transmits orbital location (almanach) + time
- 50bits/s, msg has 1500 bits → 12.5 minutes



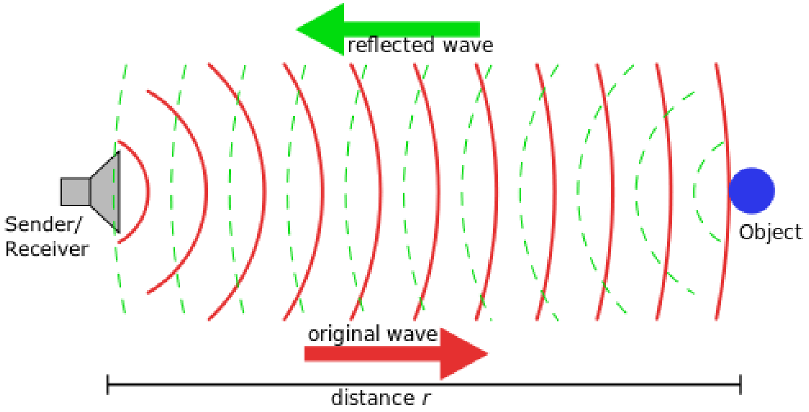
http://en.wikipedia.org/wiki/File:ConstellationGPS.gif

GPS

- Position from pseudorange
  - Requires measurements of 4 different satellites
  - Low accuracy (3-15m) but absolute
- Position from pseudorange + phase shift (RTK/dGPS)
  - Very precise (<1mm)
  - Position is relative to a reference station

Ultrasound Range Sensors

- Emit signal to determine distance along a ray
- Make use of propagation speed of ultrasound
- Traveled distance is given by speed of sound (v=340m/s)



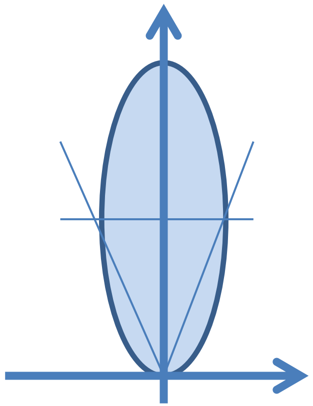
$$d = \frac{v\Delta t}{2}$$

http://en.wikipedia.org/wiki/File:Sonar_Principle_EN.svg

Ultrasound Range Sensors

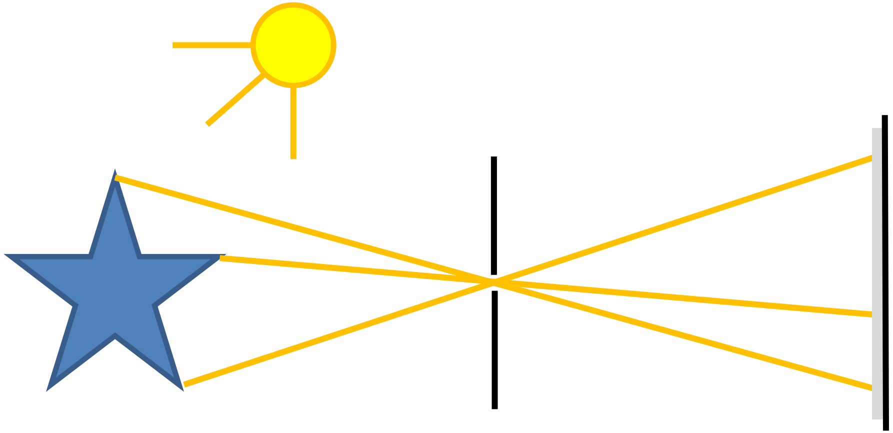
- Range between 12cm and 5m
- Opening angle around 20 to 40 degrees
- Problems: multi-path propagation, absorption
- Lightweight and cheap

http://www.parallax.com/product/28015



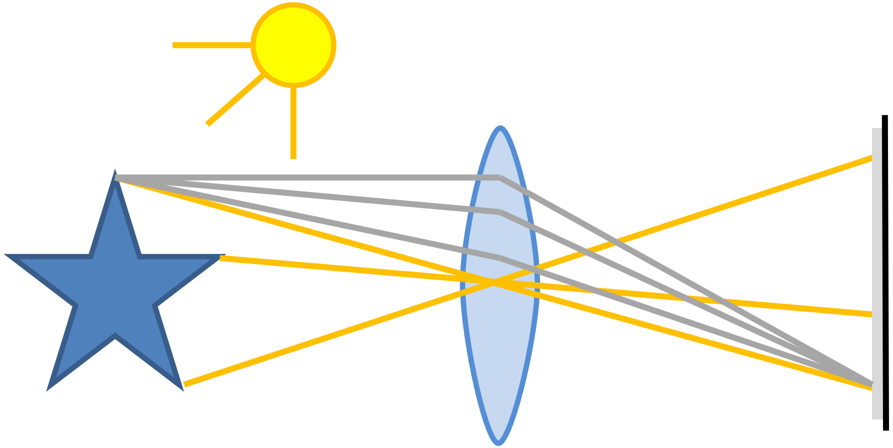
Cameras

- Pinhole Camera
- Lit scene emits light
- Film/sensor is light sensitive



Lens Camera

- Lit scene emits light
- Film/sensor is light sensitive
- A lens focuses rays onto the film/sensor



Lens Distortions

- Radial distortion of the image
  - Caused by imperfect lenses
  - Deviations are most noticeable for rays that pass through the edge of the lens

Lens Distortions

- Radial distortion of the image
  - Caused by imperfect lenses
  - Deviations are most noticeable for rays that pass through the edge of the lens
- Typically compensated with a low-order polynomial

$$\hat{x}_c = x_c(1 + \kappa_1 r_c^2 + \kappa_2 r_c^4)$$

$$\hat{y}_c = y_c(1 + \kappa_1 r_c^2 + \kappa_2 r_c^4)$$

Camera Calibration

- Pinhole model

$$\tilde{\mathbf{x}} = \begin{pmatrix} f_x & s & c_x & 0 \\ 0 & f_y & c_y & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix} \tilde{\mathbf{p}}$$

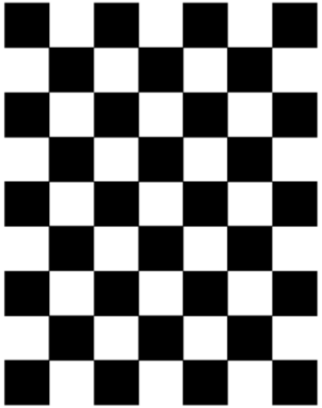
- Distortion model

$$\hat{x}_c = x_c(1 + \kappa_1 r_c^2 + \kappa_2 r_c^4)$$
$$\hat{y}_c = y_c(1 + \kappa_1 r_c^2 + \kappa_2 r_c^4)$$

- How can we determine these parameters?

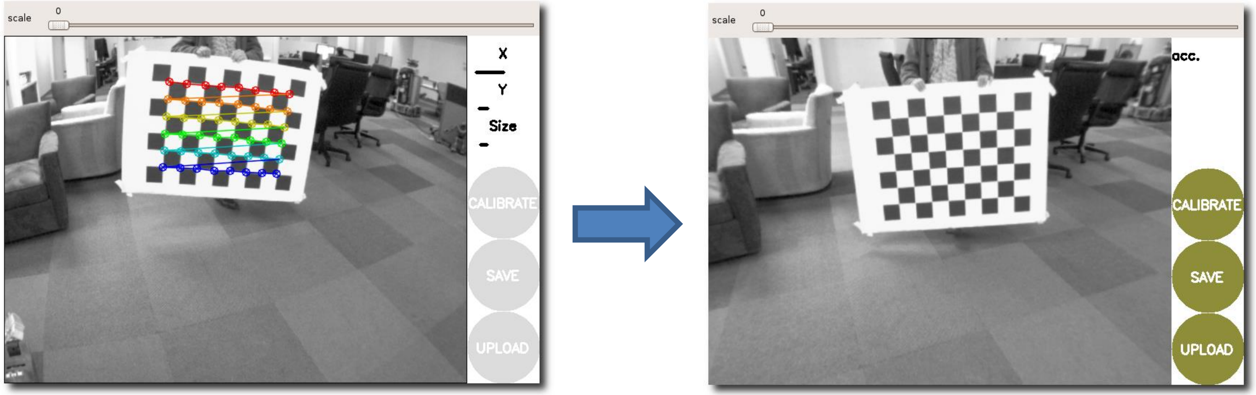
Camera Calibration

- Collect n corresponding observations between
  - 3D points $\mathbf{p}_1, \ldots, \mathbf{p}_n$ (3D location in world coordinates)
  - 2D points $\mathbf{x}_1, \ldots, \mathbf{x}_n$ (on the image plane)
- Typically using a calibration board



Camera Calibration

- Every observation $\mathbf{x}_i, \mathbf{p}_i$ produces two constraints
- Solve for f_x, f_y, c_x, c_y + distortion coefficients κ_1, κ_2



Lessons Learned

- Measure attitude, velocity and position with IMUs
- Measure distances with range sensors
- Measure position using GPS
- Camera calibration