Elective in Robotics

State Estimation

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Outline

- Sensors
- Key state estimates
  - attitude
  - velocity
  - position

Sensors (1/4)

basic instrumentation for state estimation

- IMU
- barometer

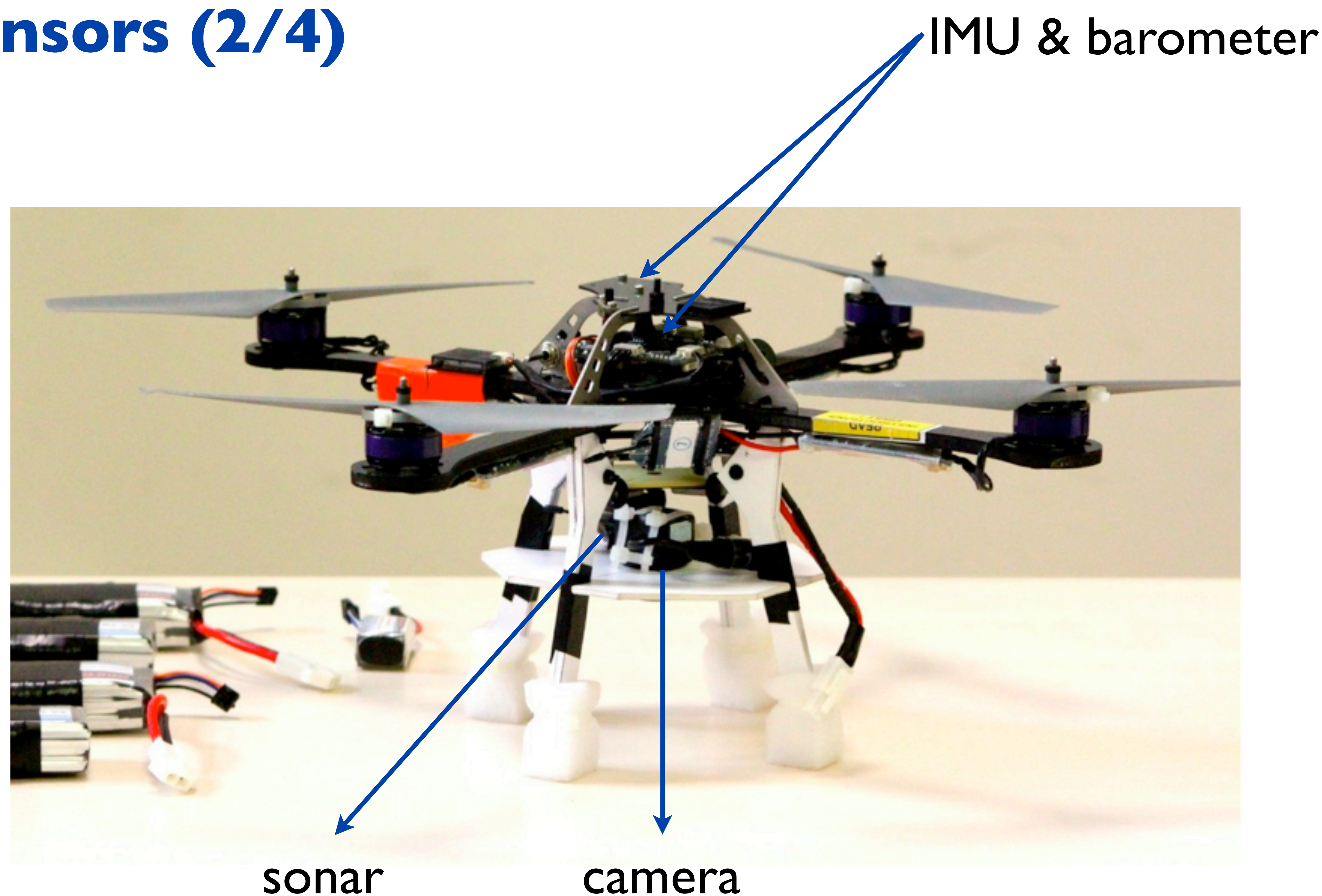
common augmentations

- sonar, laser, infrared (for eight measurements)
- monocular camera

less common equipment

- RGB-D sensors (like Kinect)
- scanning laser range finders
- GPS
- VICON

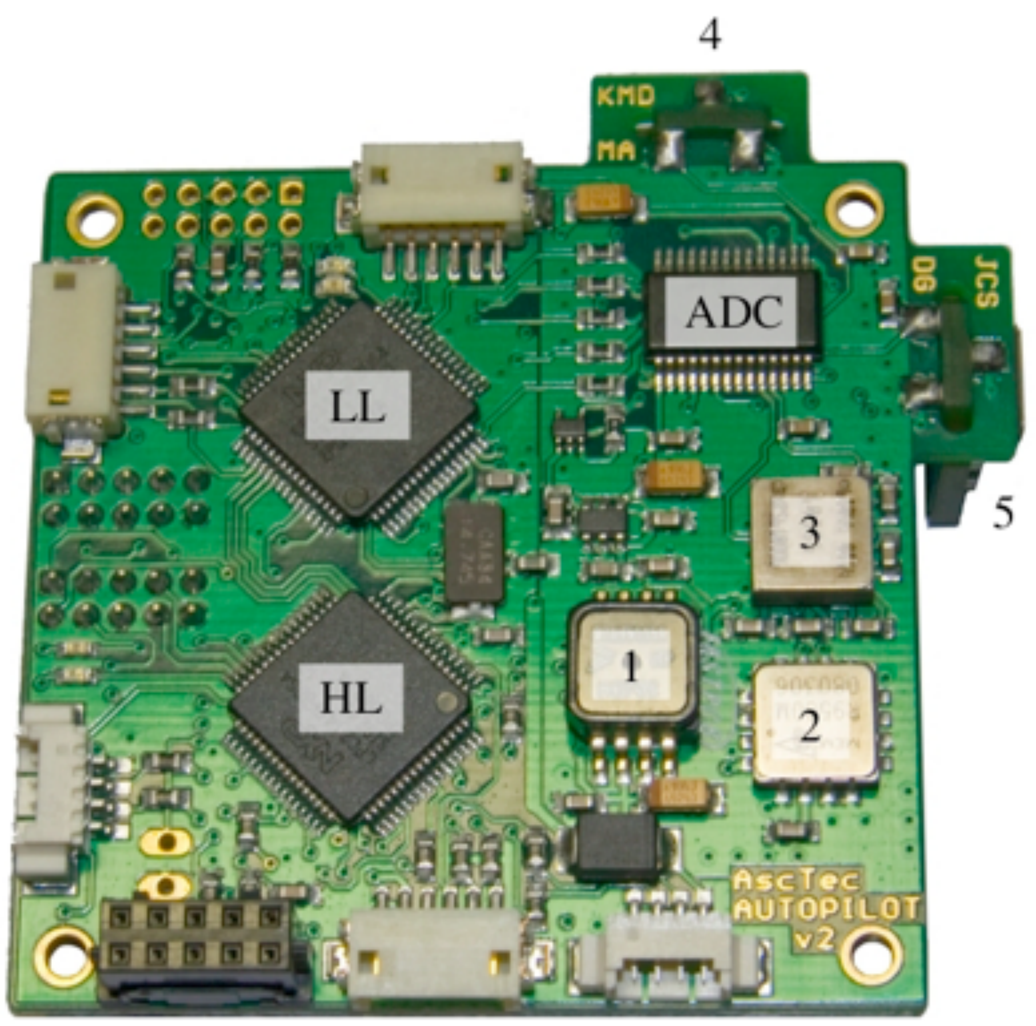
Sensors (2/4)



Sensors (3/4)

IMU

Humming Bird (IMU strap down configuration)



(2) accelerometer (x, y, z)

gyroscope

(3) yaw

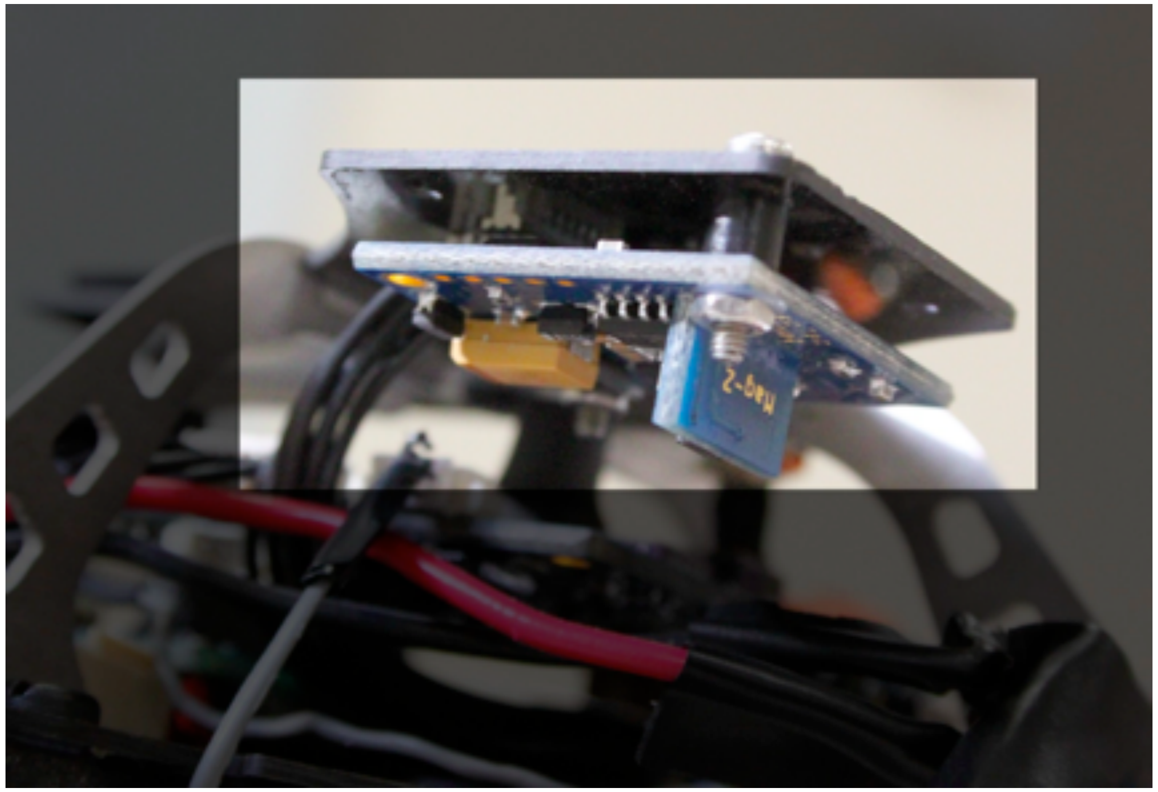
(4) pitch

(5) roll

Sensors (4/4)

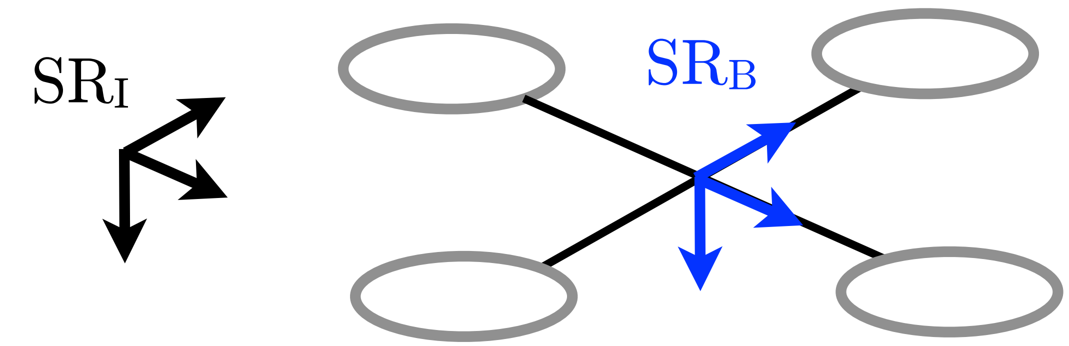
IMU

Humming Bird



3D-MAG: three-axis compass

Attitude estimation



rate gyro

- measures the angular velocity of $\mathrm{SR_B}$ relative to $\mathrm{SR_I}$, expressed in $\mathrm{SR_B}$

$$\Omega_{\mathrm{IMU}} = \Omega + b_\Omega + \eta \in \mathrm{SR_B}$$

accelerometer

- measures the instantaneous linear acceleration of $\mathrm{SR_B}$ due to exogenous forces

$$\begin{aligned} a_{\mathrm{IMU}} &= R^T(\dot{v} - g\,\vec{\boldsymbol{z}}_{\mathrm{I}}) + b_a + \eta_a \in \mathrm{SR_B} \\ &\simeq -\frac{T}{m}\,\vec{\boldsymbol{z}}_{\mathrm{I}} - \frac{T}{m} D R^T v \end{aligned}$$

low-frequency component

$$\bar{a}_{\mathrm{IMU}} \equiv -\frac{T}{m} R^T\,\vec{\boldsymbol{z}}_{\mathrm{I}}$$

constant biases

measurement noise

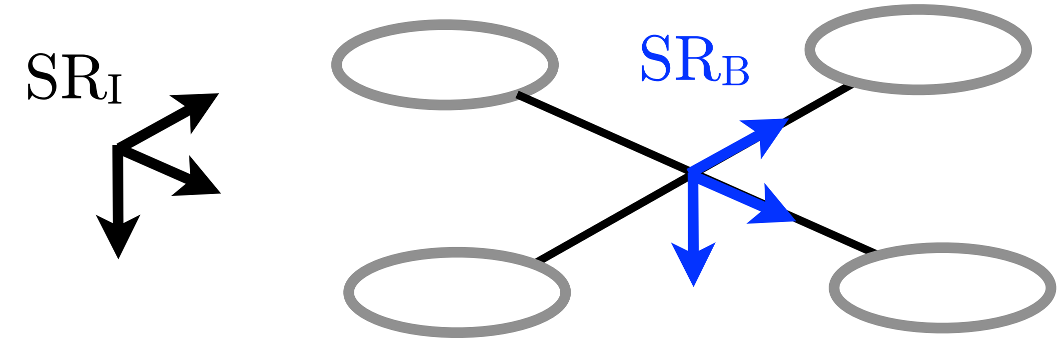
magnetometer

- provides measurements of the ambient magnetic field

$$m_{\mathrm{IMU}} = R^T\,{}^{\mathrm{I}}m + B_m + \eta_m \in \mathrm{SR_B}$$

local magnetic disturbance

Attitude estimation



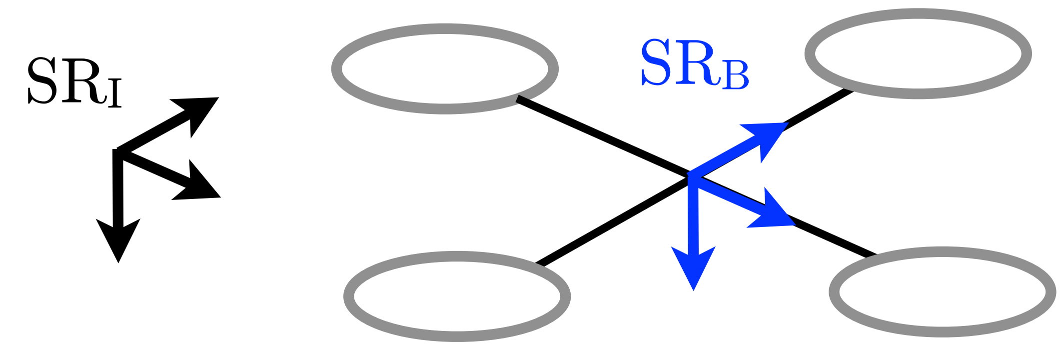
state observer

$$\begin{aligned}
\dot{\hat{R}} &= \hat{R}(\Omega_{\mathrm{IMU}} - \hat{b})_\times - \alpha \\
\dot{\hat{b}} &= k_b \alpha \\
\alpha &= (\frac{k_a}{g^2}((\hat{R}^T\ \vec{\boldsymbol{z}}_{\mathrm{I}}) \times \bar{a}_{\mathrm{IMU}}) + \frac{k_m}{|^{\mathrm{I}}m|^2}((\hat{R}^T\ {}^{\mathrm{I}}m) \times m_{\mathrm{IMU}})_\times + \cdots
\end{aligned}$$

possible contributions from other sensors

uses high frequency part of gyro and low-frequency of accelerometer and magnetometer

Velocity estimation



hyp.: horizontal flight

$$ {}^{\mathrm{I}}a_{\mathrm{IMU}} = Ra_{\mathrm{IMU}} \simeq \hat{R}a_{\mathrm{IMU}} \simeq -g\hat{R}\,\vec{\boldsymbol{z}}_{\mathrm{I}} - g\hat{R}D\hat{R}^{T}v $$

$$ \Downarrow $$

$$ v = -\frac{1}{g}(\hat{R}D\hat{R}^{T})^{-1}({}^{\mathrm{I}}a_{\mathrm{IMU}} + g\hat{R}\,\vec{\boldsymbol{z}}_{\mathrm{I}}) $$

$$ \dot{\hat{v}} = -g(\hat{R}\,\vec{\boldsymbol{z}}_{\mathrm{I}} + \hat{R}D\hat{R}^{T}\hat{v}) - k_w(\hat{v} - v) $$

Position estimation

- height and position in the plane are often decoupled
- absolute: barometer, limited information from IMU, GPS, VICON,...
- relative: acoustic, laser-ranging or infrared, RGB-D cameras, SLAM

  - measures provided by sensors are often fused in a Kalman filter (see Matlab simulations...)

References

R. Mahony, V. Kumar, P. Corke, "Multirotor Aerial Vehicles: Modeling, Estimation, and Control of Quadrotor," IEEE Robotics & Automation Magazine, vol.19, no.3, pp. 20-32, Sept. 2012.