

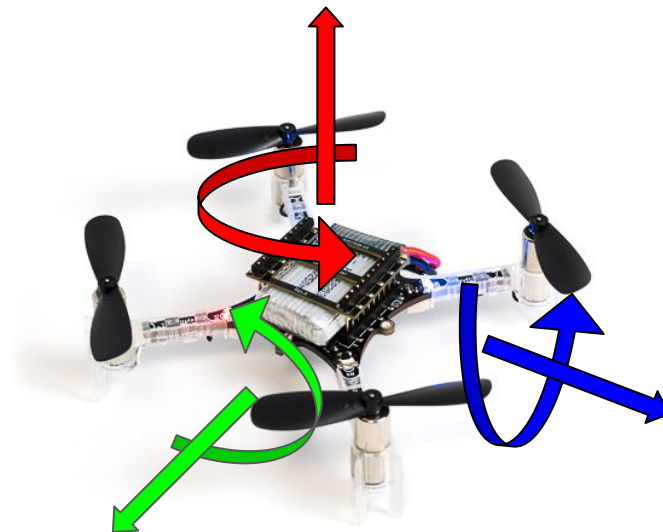
# The kalman estimator

# Goal

An overview of the Kalman state estimator in the Crazyflie firmware

# What is an estimator?

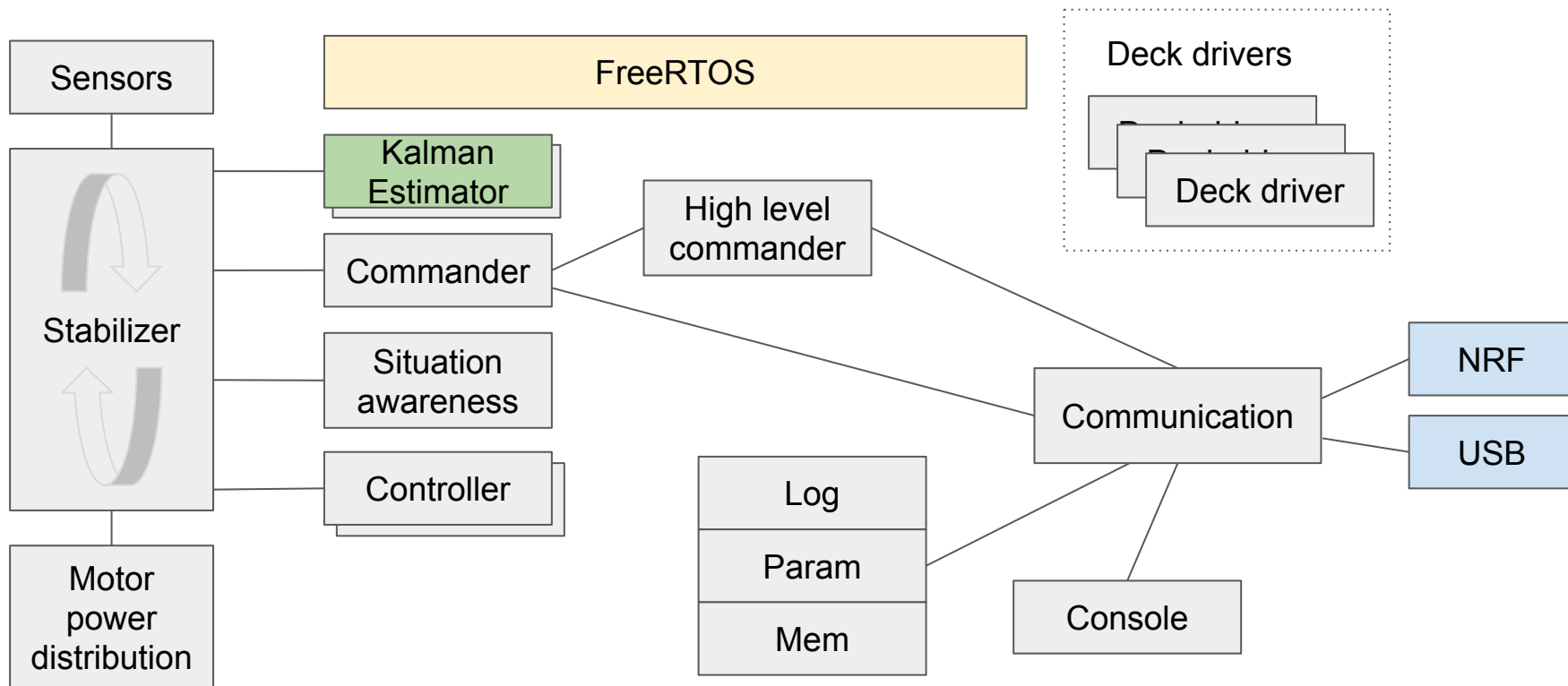
- Estimate current pose
  - Position
  - Orientation (roll, pitch, yaw)
- Input from sensors
  - Sensor fusion



# Estimators in the Crazyflie

- Plugin system
- Complementary
  - Basic
  - Robust
  - Good for manual flight
  - Not full position information
- Kalman
  - Supports more sensors
  - Good for autonomous flight

# Crazyflie firmware overview



# The Kalman estimator

- Based on two papers from ETH Zurich<sup>1,2</sup>
- Originally implemented by Mike Hamer at ETH
- Has been extended over time

<sup>1</sup>Mueller, Mark W., Michael Hamer, and Raffaello D'Andrea. "Fusing ultra-wideband range measurements with accelerometers and rate gyroscopes for quadcopter state estimation." *2015 IEEE International Conference on Robotics and Automation (ICRA)*. IEEE, 2015.

<sup>2</sup>Mueller, Mark W., Markus Hehn, and Raffaello D'Andrea. "Covariance correction step for kalman filtering with an attitude." *Journal of Guidance, Control, and Dynamics* 40.9 (2016): 2301-2306.

# Model and state

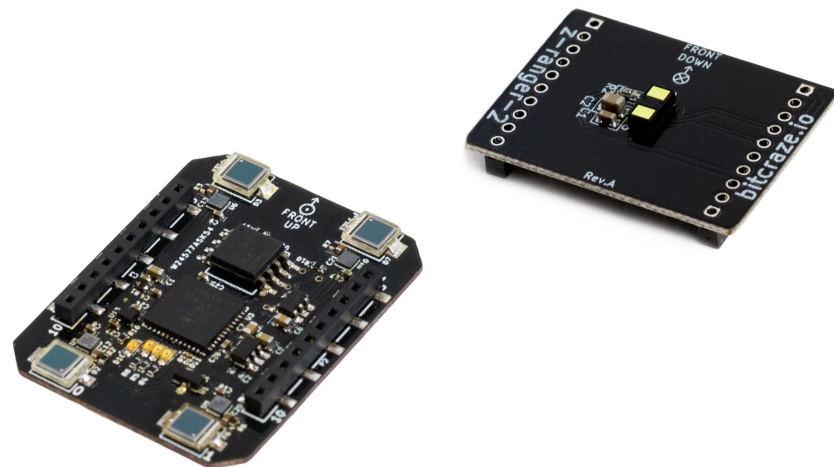
- Model
  - Describes the physical behaviour of the Crazyflie
    - Flying
    - Carried
  - Quadcopter
- State
  - Position (X, Y, Z)
  - Velocity (X, Y, Z)
  - Attitude error (X, Y, Z)

# Sensor input

- Accelerometers (X, Y, Z)
- Gyros (X, Y, Z)
- Barometer - not used
- Range sensors
- Optical flow sensor
- LPS Two Way Ranging
- LPS TDoA
- Lighthouse
- External pose input
  - Mocap system



BMI088 (IMU)



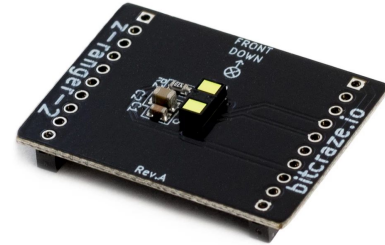
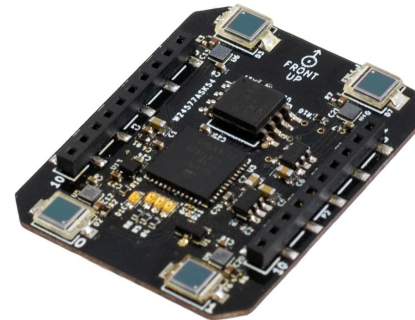


# Sensor input is weighted

- Sensors with low noise have stronger influence
- Sensors with high noise have less influence
- Each sensor adds some information, but maybe not the full position
- All information is fused into one solution, the state

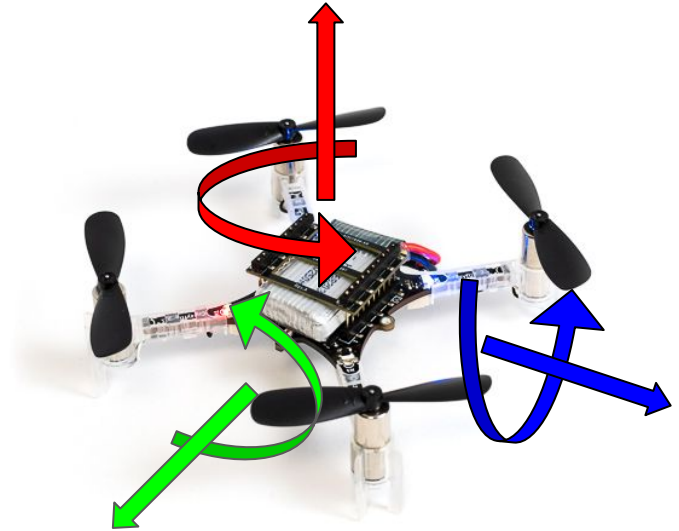


BMI088 (IMU)



# The state

- Probabilistic view of current situation
- Updated at 100 Hz
- New information updates the state
- Sensor input is paired with a probability

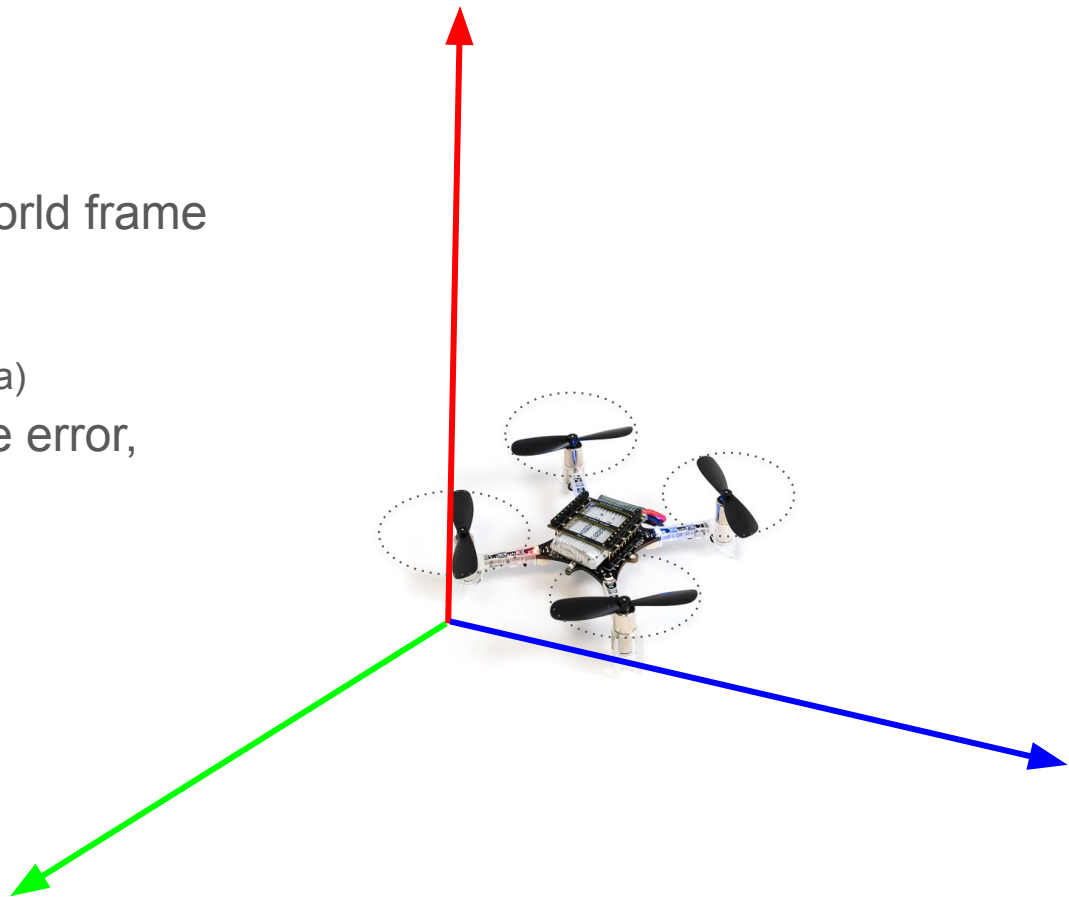


# Processing

- Sensor input is queued
- Processing done as part of the stabilizer loop
- Sensor data processed when the state is updated (1000 Hz)
- Prediction step at 100Hz

# Externalization

- The state is externalized to world frame
  - Position
  - Velocity
  - Acceleration (accelerometer data)
- The state contains the attitude error, integrated for easy access
  - Rotation matrix
  - Quaternion



# Conclusions

- Fuses sensordata
- Continuously estimates the pose
- Full state estimator