Data Filtering for Sensor Fusion in the context of orientation computation

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Universität Hamburg
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MEMS

Microelectromechanical Systems

Include Acelerometer, Magnetometer, Gyroscope and other sensors

Have Hardware Accelerators for filters and sensor fusion algorithms

Courtesy of [1]

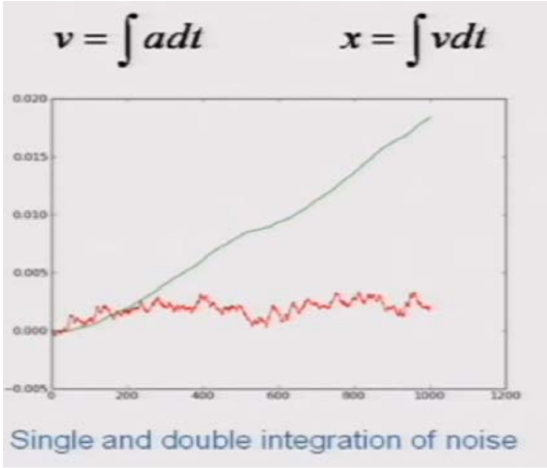
Accelerometer

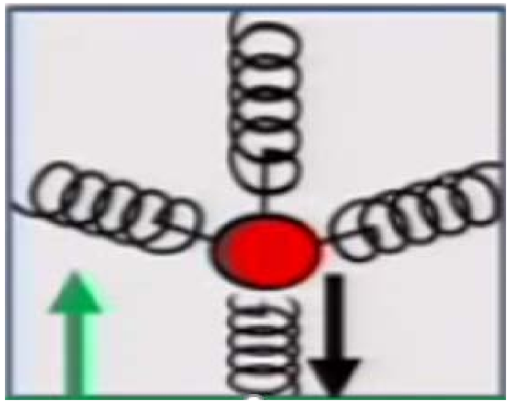
Measures Linear Acceleration + Gravity

Sensor Fusion helps split these components

Raw data will always have a bias because of the Gravity component

Used for computing motion gestures





Courtesy of [2]

Magnetometer

Magnetic Declination: Magnetic north vs Geographic north

Magnetic Inclination: Magnetic Field vector is tilted with respect to the Horizontal axis

Lots of noise from: metal components in the device, battery, other electrical and magnetic components

Used in conjunction with accelerometer to correct the drift of the gyroscope

Courtesy of [3]

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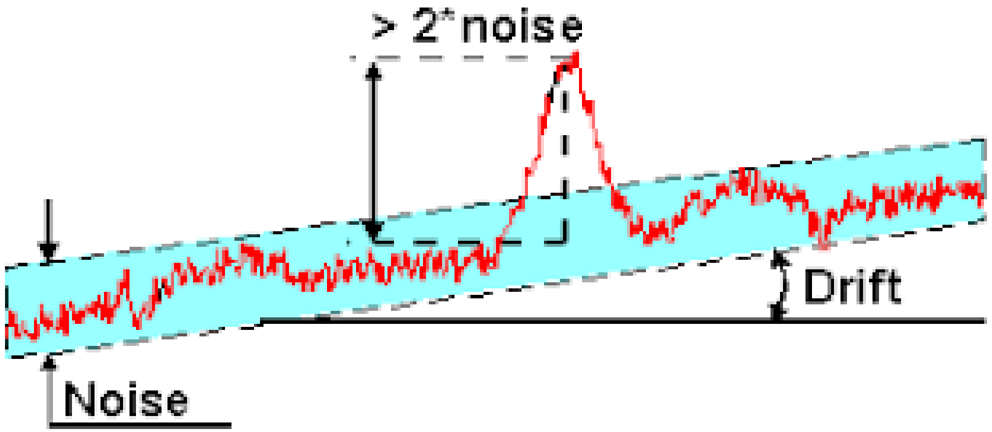
Gyroscope

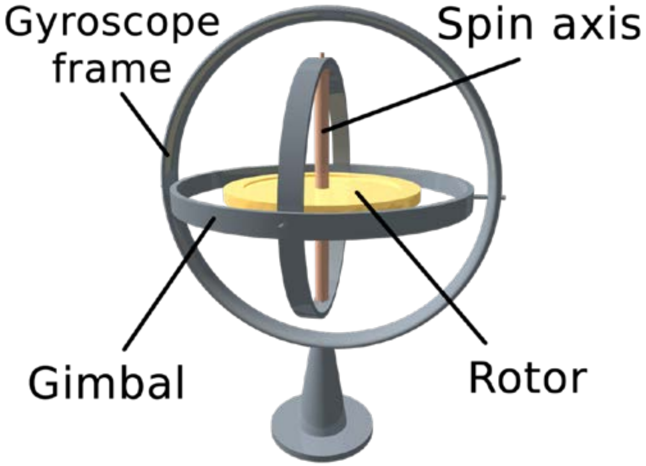
Senses angular velocity using the Coriolis Effect

It has good dynamic response (because of low noise/ the noise is integrated)

Suffers from drift (because of noise integration)



Courtesy of [4]



Courtesy of [5]

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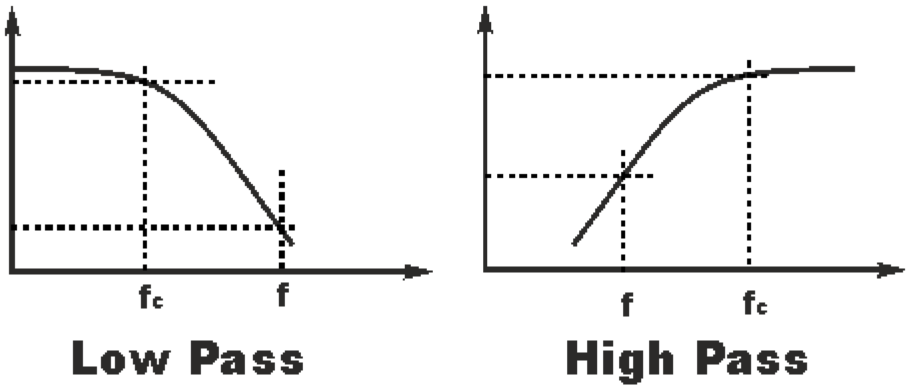
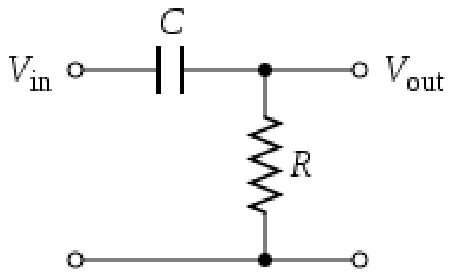
Data Filtering

- Using high pass and low pass filters (not state of the art)





(In digital form of course ☺)

Courtesy of [6]

Courtesy of [7]

- Using Kalman Filters (state of the art)

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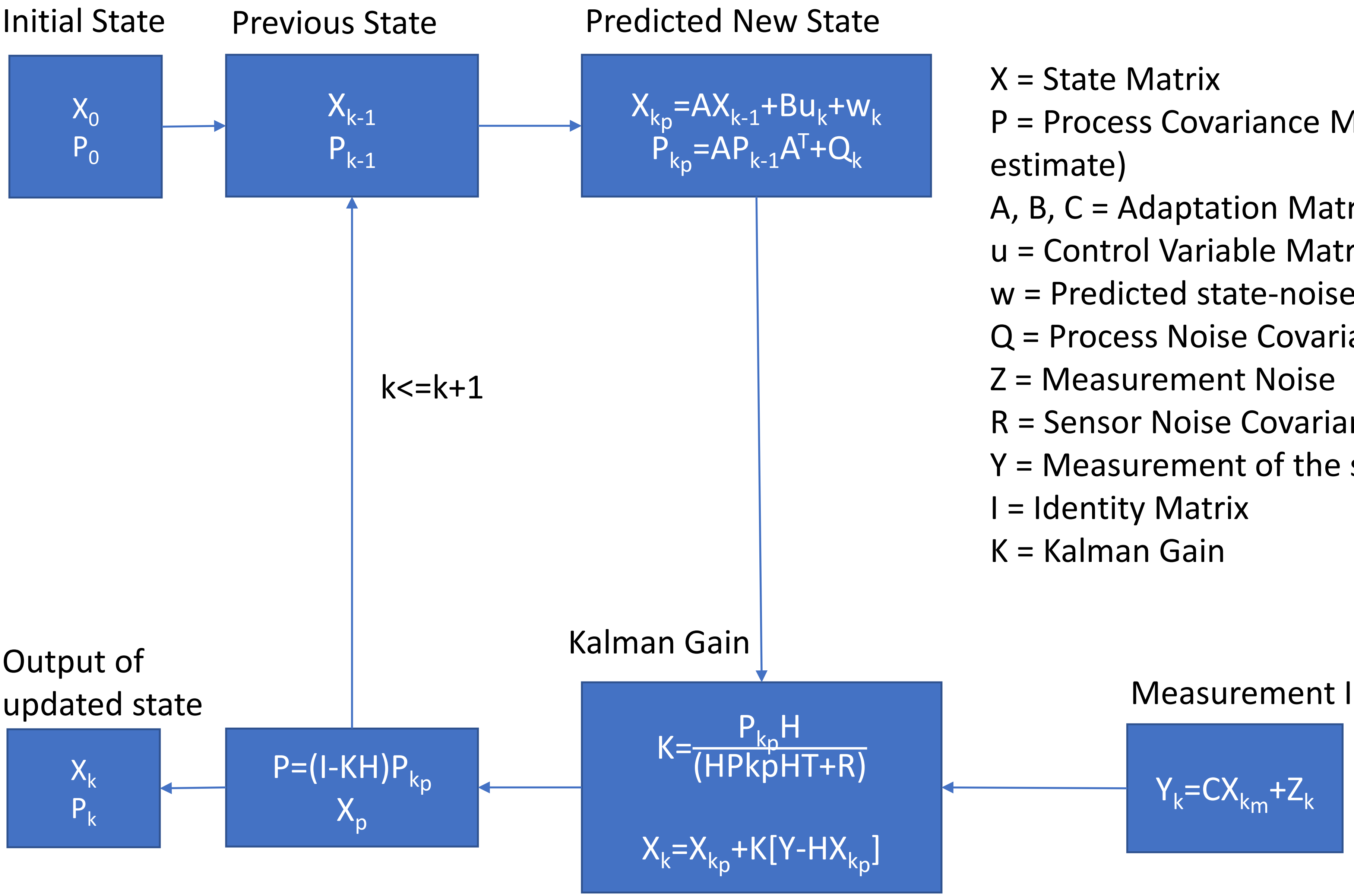
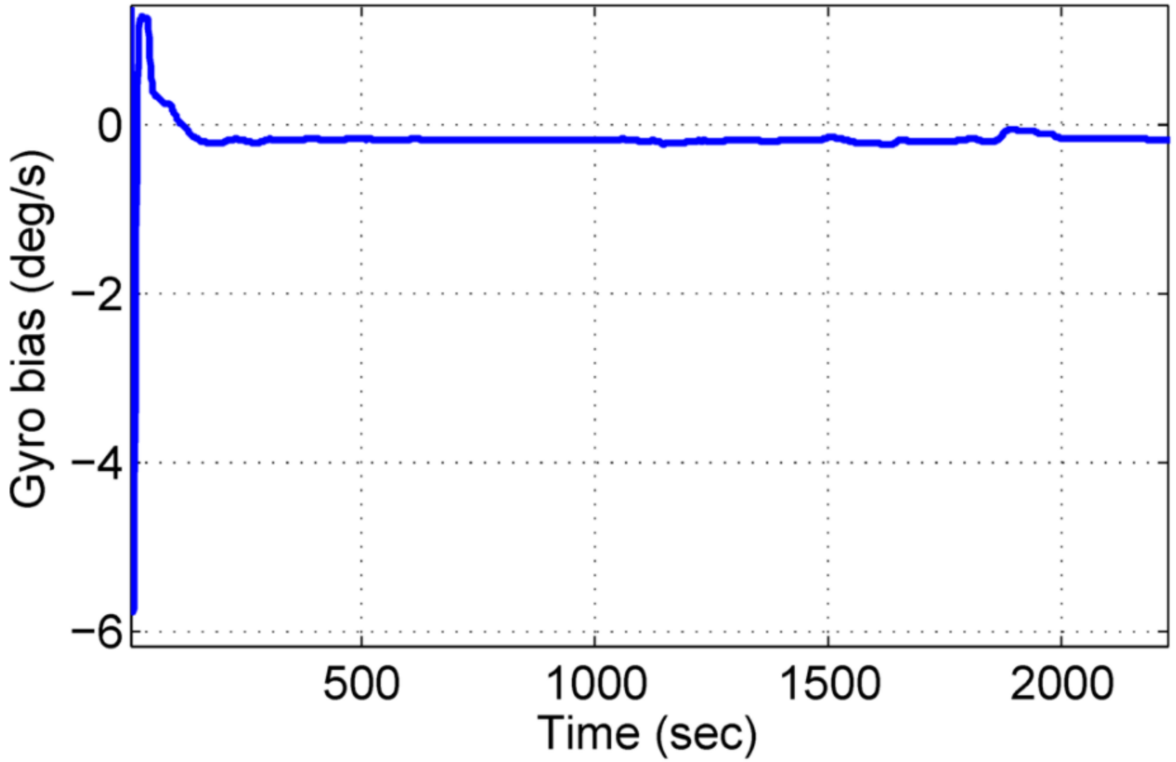
Kalman Filter



X = State Matrix
P = Process Covariance Matrix (Represents error in the estimate)
A, B, C = Adaptation Matrices
u = Control Variable Matrix
w = Predicted state-noise matrix
Q = Process Noise Covariance Matrix
Z = Measurement Noise
R = Sensor Noise Covariance Matrix (Measurement Error)
Y = Measurement of the state
I = Identity Matrix
K = Kalman Gain

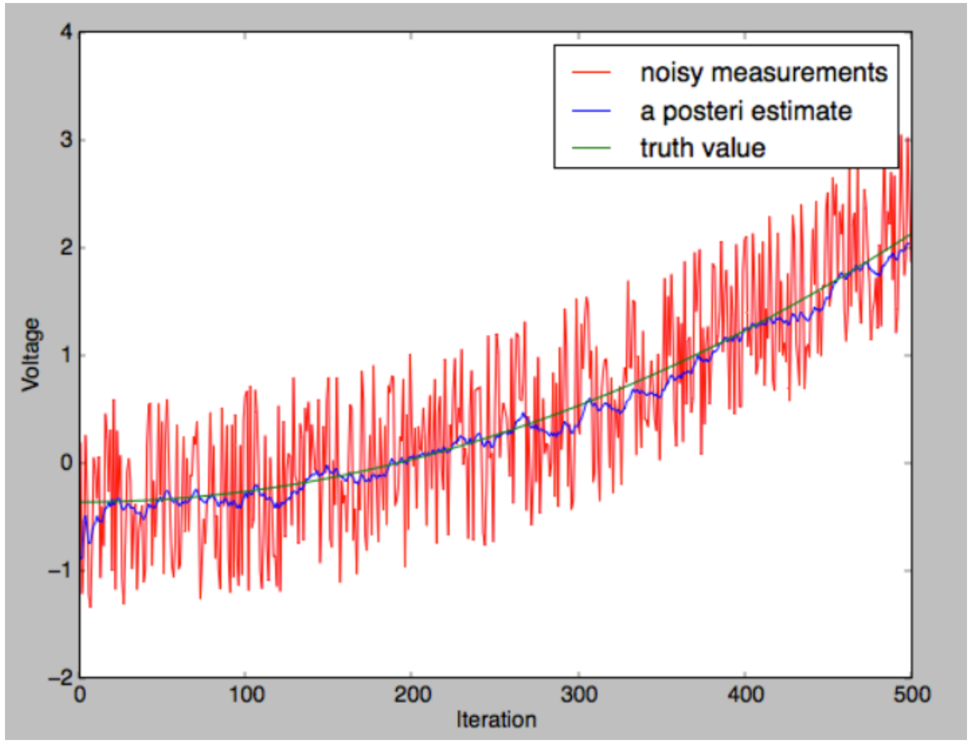
Kalman Filter Properties

Kalman Filter converges very fast, no matter what the initial estimates were (i.e. initial X_0)



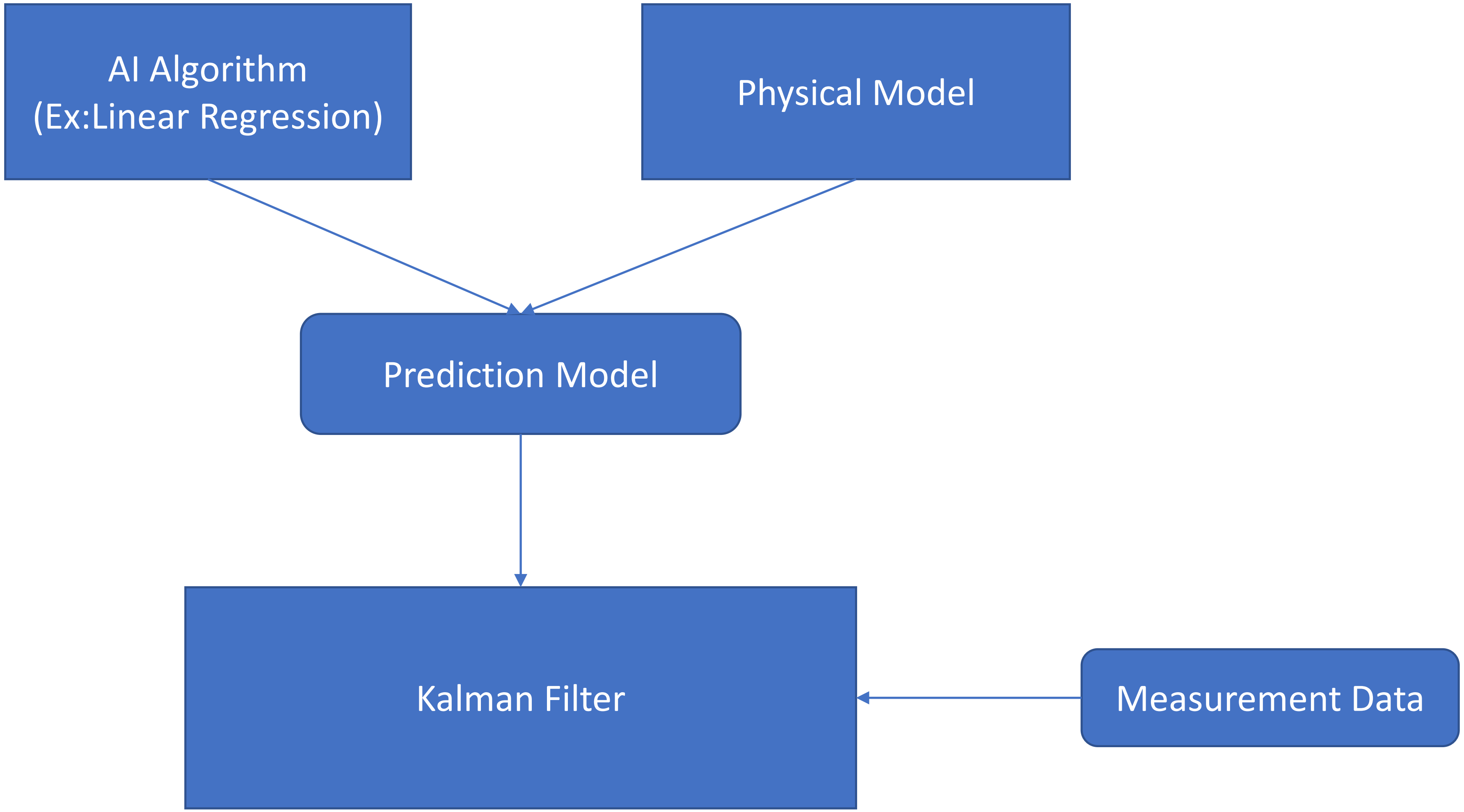
Courtesy of [10]

Kalman Filter ignores outlier measurement points



Courtesy of [11]

The Model


AI Algorithm
(Ex:Linear Regression)
Physical Model
Prediction Model
Kalman Filter
Measurement Data

Physical Model for 3D Motion

$$\mathbf{r} = \mathbf{r}_0 + \mathbf{v}t - \frac{1}{2}\mathbf{a}t^2$$

$$X_k = \begin{bmatrix} 1 & 0 & 0 & \Delta T & 0 & 0 \\ 0 & 1 & 0 & 0 & \Delta T & 0 \\ 0 & 0 & 1 & 0 & 0 & \Delta T \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ x' \\ y' \\ z' \end{bmatrix} + \begin{bmatrix} \frac{1}{2}\Delta T^2 & 0 & 0 \\ 0 & \frac{1}{2}\Delta T^2 & 0 \\ 0 & 0 & \frac{1}{2}\Delta T^2 \\ \Delta T & 0 & 0 \\ 0 & \Delta T & 0 \\ 0 & 0 & \Delta T \end{bmatrix} \begin{bmatrix} a_x \\ a_y \\ a_z \end{bmatrix}$$

Courtesy of [12]

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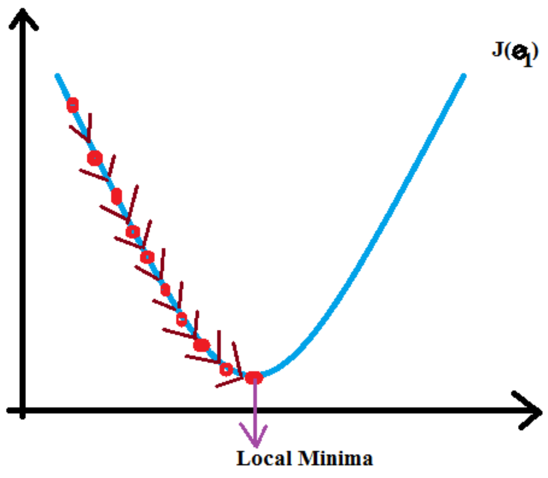
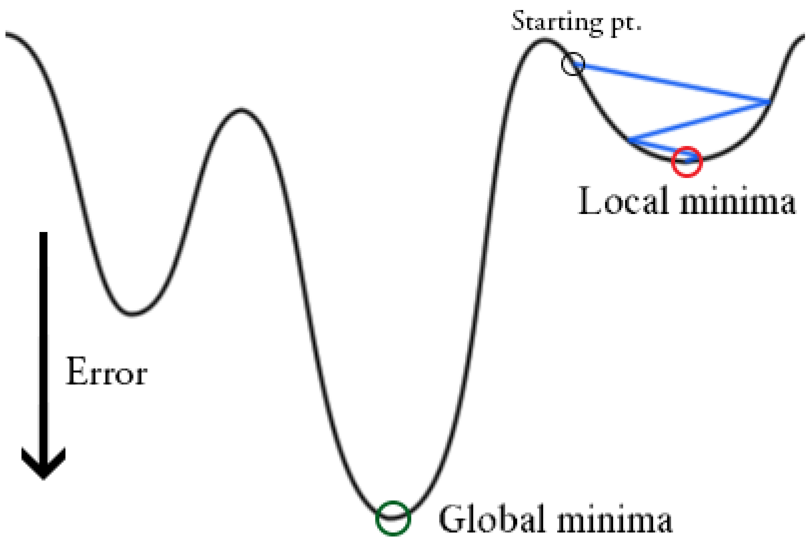
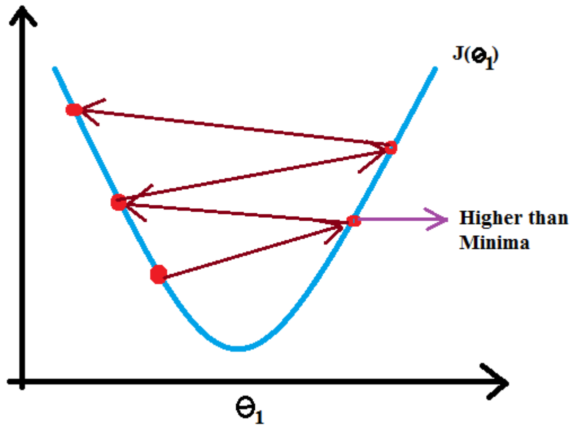
Prediction Model for MEMS chip: Madgwick Filter



Courtesy of [13]



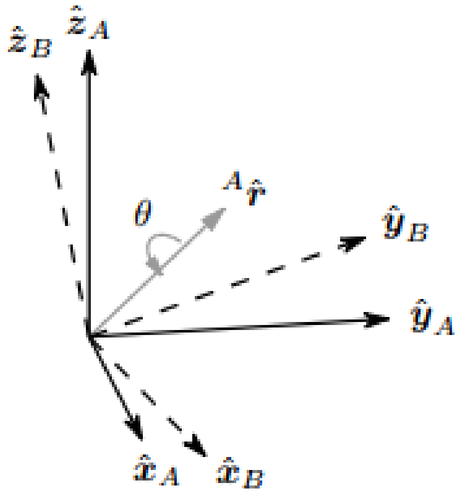
Courtesy of [14]



Courtesy of [13]

Madgwick Filter uses Quaternions

Intuition: Vector in 3D that can also be rotated at an angle theta



Courtesy of [15]

Q = <$\cos(\frac{\theta}{2})$, $x\sin(\frac{\theta}{2})$, $y\sin(\frac{\theta}{2})$, $z\sin(\frac{\theta}{2})$>

Similar concept to an Axis-Angle rotation

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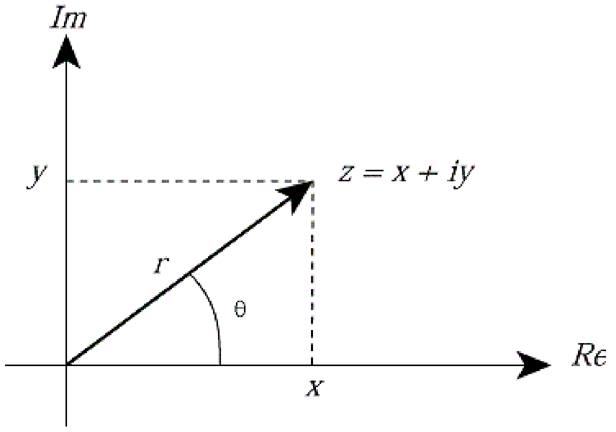
Why Quaternions ?

Math is nice for expressing complex orientation !

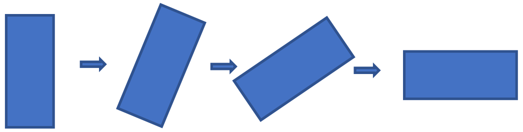


Courtesy of [16]

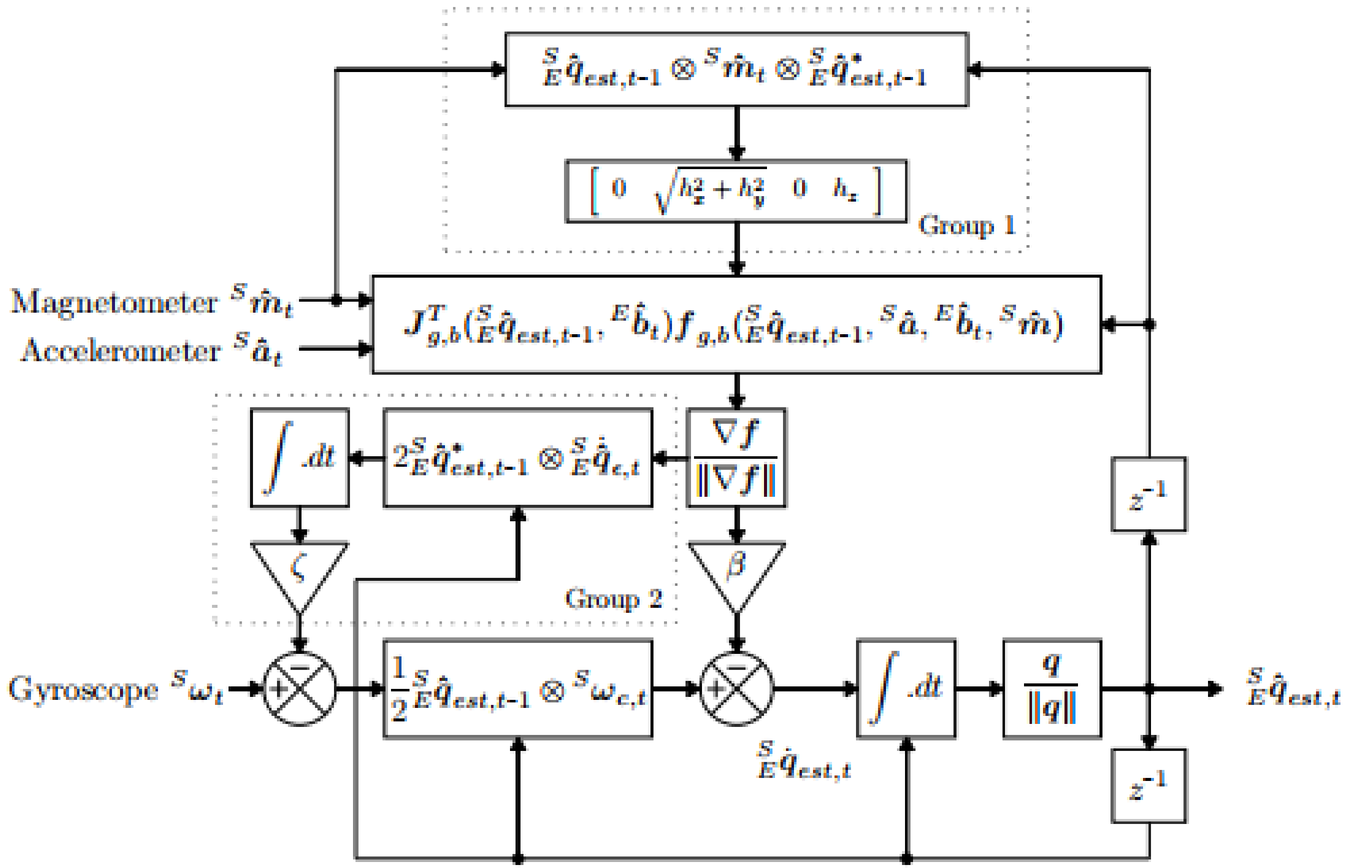
$$r * e^{i\theta}$$ useful for rotation

Q = w + (i*x+j*y+k*z)

Interpolation, addition, subtraction,...



Data Fusion and Integration



Courtesy of [15]

Questions ?

References

[1] MPU-6500. Six-Axis (Gyro + Accelerometer) MEMS MotionTracking Device.
URL https://www.invensense.com/products/motion-tracking/6-axis/mpu-6500/

[2] Sachs, David. (August 2, 2010) „ *Sensor Fusion on Android Devices: A Revolution in Motion Processing*“. Google Tech Talk

[3] Compass. URL https://pixabay.com/en/compass-east-north-south-west-152121/

[4] Noise and drift. URL http://hplc.chem.shu.edu/NEW/HPLC_Book/Detectors/det_nise.html

[5] Gyroscope. URL https://en.wikipedia.org/wiki/Gyroscope

[6] Poole, Ian. High Pass Filter Design.
URL http://www.radio-electronics.com/info/rf-technology-design/rf-filters/highpass-filter-design.php

[7] RC High Pass Filter. URL http://hyperphysics.phy-astr.gsu.edu/hbase/electric/filcap.html

[8] Kim, Phil. *Kalman filter for beginners: with MATLAB examples*. CreateSpace, 2011

[9] Brookner, Eli. "Kalman Filter." *Tracking and Kalman Filtering Made Easy*

References

[10] Karamat, T.B., Atia, M.M. and Noureldin, A., 2015.
An Enhanced Error Model for EKF-Based Tightly-Coupled Integration of GPS and Land Vehicle's Motion Sensors.
Sensors, *15*(9), pp.24269-24296. URL http://www.mdpi.com/1424-8220/15/9/24269/htm

[11] Lobdell, Scott. August 16, 2014. URL http://scottlobdell.me/2014/08/kalman-filtering-python-reading-sensor-input/

[12] Condliffe, Jamie. Tech CEO Space Race Intensifies. March 3, 2017.
URL https://www.technologyreview.com/s/603783/tech-ceo-space-race-intensifies/

[13] Linear Regression in one variable-Gradient Descent. November 19, 2014.
URL https://wingshore.wordpress.com/2014/11/19/linear-regression-in-one-variable-gradient-descent-contd/

[14] Training neural networks: back-propagation vs. genetic algorithms. March 9, 2014.
URL https://thinkingandcomputing.com/posts/genetic-algorithms-neural-networks.html

[15] Madgwick, Sebastian. "An efficient orientation filter for inertial and inertial/magnetic sensor arrays."
Report x-io and University of Bristol (UK) 25 (2010).

[16] EECS20N: Signals and Systems, Polar coordinates.
URL https://ptolemy.eecs.berkeley.edu/eecs20/sidebars/complex/polar.html