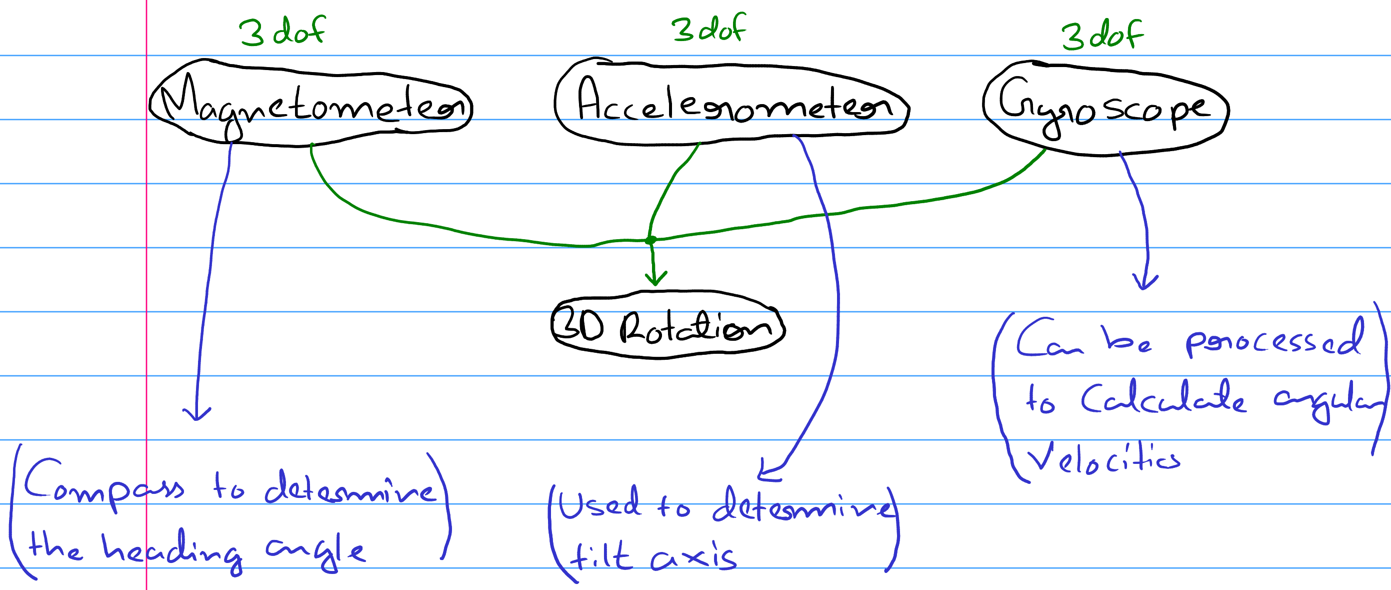
# Imu filters

Most common filters used are:
- Complementary filter
- Kalman filter




⇒ Each sensor has its own advantage under different static and dynamic scenarios.

## 1. Accelerometer

⇒ Very accurate in long term.

⇒ Roll and Pitch angles can be calculated precisely when the object is stand still on earth.

⇒ However when the sensor is moving, the moving acceleration will impact the rotation calculation.

↳ However, if we apply a low pass filter to the output of the accelerometer, most of the noise and external force acceleration will be removed.

## 2. Magnetometer

⇒ Incorrect data when near external magnetic field source. {otherwise good}

↳ Yaw can be calculated easily if IMU is flat, but if it is not flat then you need accelerometer data to calculate Yaw.

## 3. Gyroscope

⇒ One problem with gyro angle estimation is that its calculation drift over time because of integration.

⇒ In addition to that, due to inertia, the gyro scale wont come back to zero when object is standstill state.

⇒ Gyro is very accurate in short term.

⇒ People usually apply highpass filter to gyroscope measurement.

## ★ Calculations

$\theta$ → Rotation about x (Roll)

$\phi$ → Rotation about y (Pitch)

$\psi$ → Rotation about z (Yaw)

$$\tan(\theta) = \frac{a_y}{a_z} \qquad \tan(\phi) = -\frac{a_x}{\sqrt{(a_y^2+a_z^2)}}$$

{Accelerometer}

$$M_x = m_x \cdot \cos(\phi) + m_z \cdot \sin(\phi)$$

$$M_y = m_x \cdot \sin(\theta) \cdot \sin(\phi) + m_y \cdot \cos(\theta) - m_z \cdot \sin(\theta) \cdot \cos(\phi)$$

$$\psi = \tan^{-1}\frac{M_y}{M_x}$$

{Magnetometer with accelerometer based tilt correction}

$$\theta = \omega_\theta * \Delta t \qquad \phi = \omega_\phi * \Delta t \qquad \psi = \omega_\psi * \Delta t$$

{Gyroscope}

## ★ Fusion method

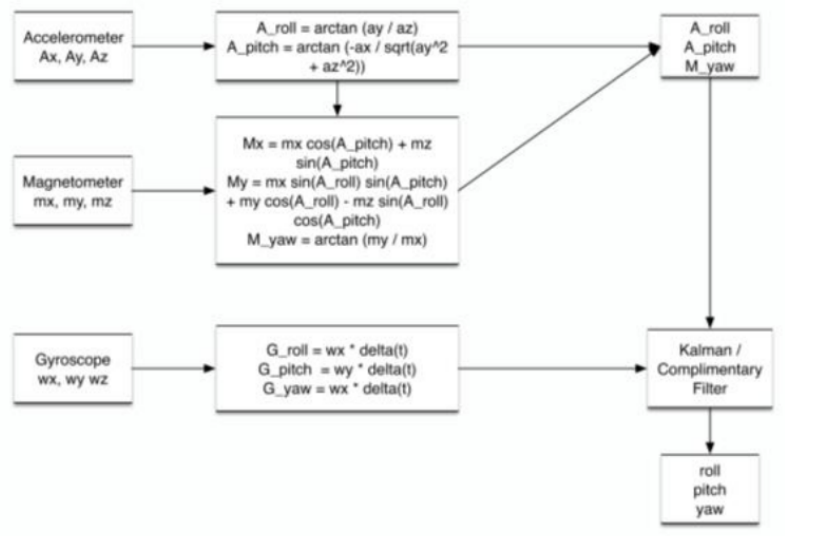



*Figure 9: Procedure's block diagram*

## 1. Complimentary Filter

⇒ It basically take advantage of each sensor and compensate for the disadvantages the other sensor have.

⇒ Accelerometer performs best with low frequency while gyroscope performs the best with high frequency.

⇒ Complimentary filter is simple and easy to use, it contain a fixed value for low pass and high pass weights.

$$CF\_angle = HP\_weight * (CF\_angle + gyro\_data * \Delta t) + LP\_weight * acc\_data$$

{Where HP_weight + LP_weight = 1}

{HP_weight should be very close to 1 and LP_weight should be very close to 0.}

{ Ex: HP_Weight = 0.98 LP_Weight = 0.02

{This is actually accelerometer + Magnetometer data}

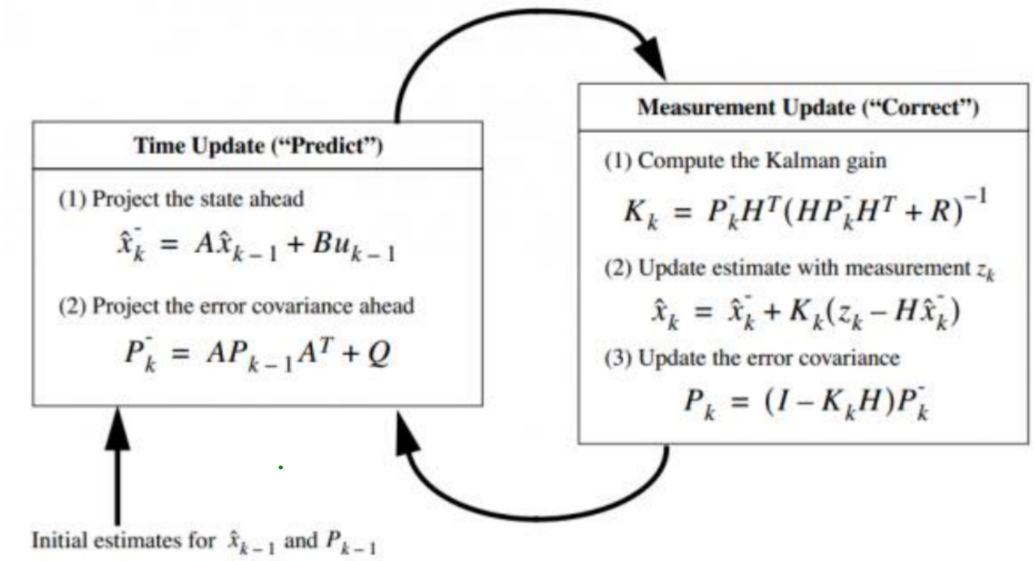
# ★ Kalman Filter

⇒ Kalman filter takes into account a series of measurements over time, and dynamically calculate and update the weight (Kalman gain).

⇒ Kalman Filter consists of two main steps:

① Prediction.
② Correction.

⇒ The three roll, pitch and yaw angle are independent; therefore each a - could be tracked separately.




⇒ This is a recursive state estimation filter which takes inputs:

$$x_{k-1} = \begin{bmatrix} \theta_k \\ \dot{\theta}_k^b \end{bmatrix} \begin{matrix} \rightarrow \text{angle} \\ \rightarrow \text{bias angular velocity.} \end{matrix}$$

{Mean}

$$P_{k-1} = \begin{bmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{bmatrix} \rightarrow \text{Covariance of } x_{k-1}$$

$$u_{k-1} = \dot{\theta} \rightarrow \text{angular velocity.}$$

$Z_k = \theta_k^z \rightarrow$ angle from sensor measurement

$\Rightarrow$ Model parameters:

$$A = \begin{bmatrix} 1 & -\Delta t \\ 0 & 1 \end{bmatrix} \quad B = \begin{bmatrix} \Delta t \\ 0 \end{bmatrix} \quad H = \begin{bmatrix} 1 & 0 \end{bmatrix}$$

$\Rightarrow$ Noise parameters:

Q = Covariance of process noise $= \begin{bmatrix} Q_\theta & 0 \\ 0 & \dot{Q}_b \end{bmatrix}$

R = Covariance of Observation noise = R_measure

$\Rightarrow$ Typical noise parameters:

$\theta_\theta = 0.001$

$\dot{\theta}_b = 0.003$

R_measure = 0.03

★ Experimental Results

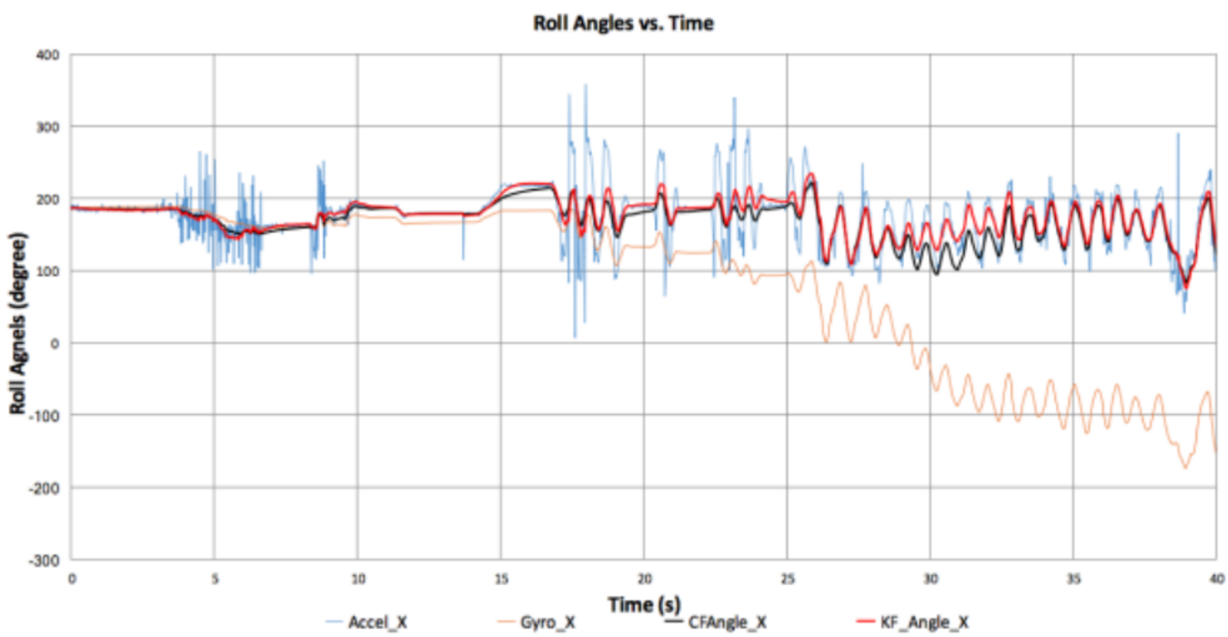



*Figure 11: Roll Angles vs. Time*

# ★ Imu data sheet

## 0. Common

⇒ Size of output data (ie. 16 bit / 8bit output)
↳ This is resolution of output data.

## 1. Gyroscope

DPS (Degree per sec)
↳ Value on full scale deflection will be given. (Example ±2000 dps)

temperature range
{Example −40°C to +85°C}

data output rate
{Example 50 Hz}

## 2. Accelerometer

Range
↳ Maximum possible value to measure {Ex: ±8g}
↳ Earths gravitational acceleration

## 3. Magnetometer

Range
↳ Maximum possible value to measure {Ex: ±8.1 gauss}