

Lecture

Sensor Technology

EE 565: Position, Navigation and Timing

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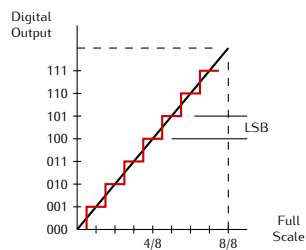
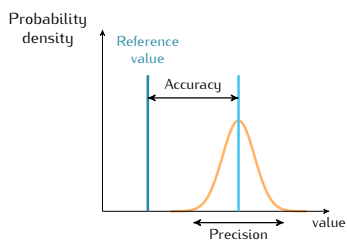
In collaboration with

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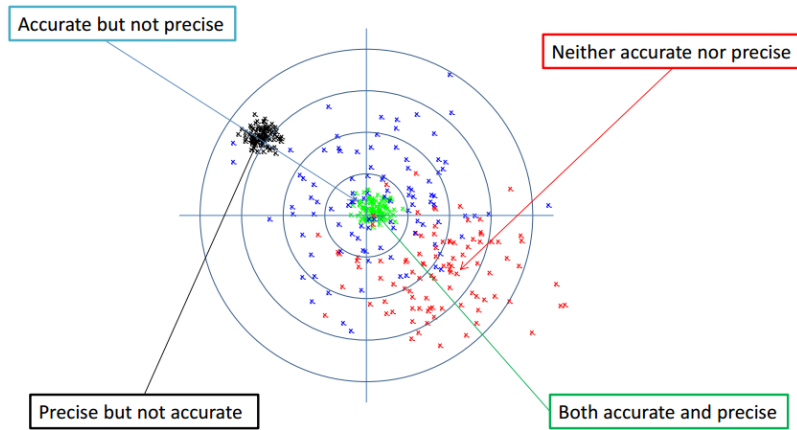
Terminology

- **Accuracy:** Proximity of the measurement to the true value
- **Precision:** The consistency with which a measurement can be obtained
- **Resolution:** The magnitude of the smallest detectable change
- **Sensitivity:** The ratio between the change in the output signal to a small change in input physical signal. Slope of the input-output fit line.
- **Linearity:** the deviation of the output from a “best” straight line fit for a given range of the sensor



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Accuracy vs Precision



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Inertial Sensors — Bias Errors

- Bias — often the most critical error
 - Fixed Bias b_{FB}
 - * Deterministic in nature and can be addressed by calibration
 - * Often modeled as a function of temperature
 - Bias Stability b_{BS}
 - * Varies from run-to-run as a random constant
 - Bias Instability b_{BI}
 - * In-run bias drift — typically modeled as random walk

Bias Errors

$$\Delta f = b_{a,FB} + b_{a,BI} + b_{a,BS} = b_a$$

$$\Delta \omega = b_{g,FB} + b_{g,BI} + b_{g,BS} = b_g$$

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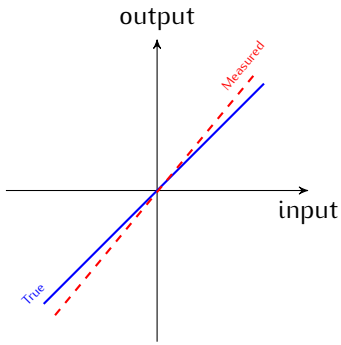
Inertial Sensors — Scale Factor Errors

- Fixed scale factor error
 - Deterministic in nature and can be addressed by calibration
 - Often modeled as a function of temperature
- Scale Factor Stability s_a (accel) or s_g (gyro)
 - Varies from run-to-run as a random constant
 - Typically given in parts-per-million (ppm)

Scale Factor Errors

$$\Delta f = s_a f, \quad \Delta \omega = s_g \omega$$

The scale factor represents a linear approximation to the steady-state sensor response over a given input range — True sensor response may have some non-linear characteristics



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Inertial Sensors — Misalignment

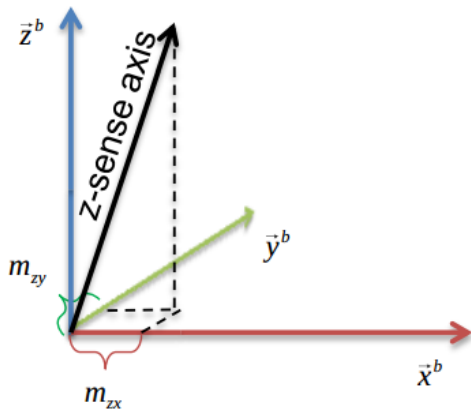
- Refers to the angular difference between the ideal sense axis alignment and true sense axis vector
 - a deterministic quantity typically given in milliradians

$$\Delta f_z = m_{a,zx} f_x + m_{a,zy} f_y$$

$$\Delta \omega_z = m_{g,zx} \omega_x + m_{g,zy} \omega_y$$

- Combining misalignment & scale factor

$$\Delta \vec{f} = \begin{bmatrix} s_{a,x} & m_{a,xy} & m_{a,xz} \\ m_{a,yx} & s_{a,y} & m_{a,yz} \\ m_{a,zx} & m_{a,zy} & s_{a,z} \end{bmatrix} \begin{bmatrix} f_x \\ f_y \\ f_z \end{bmatrix} = M_a \vec{f}_{ib}^b$$



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Inertial Sensors — Cross-Axis Response

- Refers to the sensor output which occurs when the device is presented with a stimulus which is vectorially orthogonal to the sense axis
- Misalignment and cross-axis response are often difficult to distinguish — Particularly during testing and calibration activities

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Inertial Sensors — Other Noise Sources

Typically characterized as additive in nature

- May have a compound form
 - white noise
 - * Gyros: white noise in rate \Rightarrow Angle Random Walk (ARW)
 - * Accels: white noise in accel \Rightarrow Velocity Random Walk (VRW)

- Quantization noise
 - * May be due to LSB resolution in ADC's
- Flicker noise
- Colored noise

Inertial Sensors — Gyro Specific Errors

- G-sensitivity
 - The gyro may be sensitive to acceleration
 - Primarily due to device mass assymetry
 - Mostly in Coriolis-based devices (MEMS)

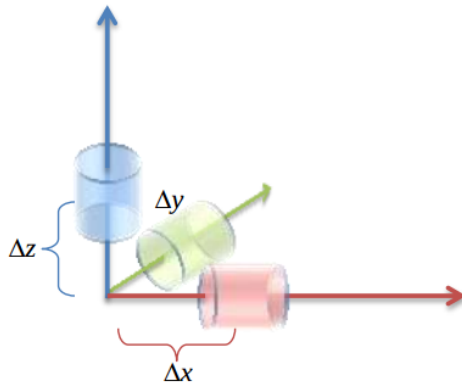
$$\Delta\vec{\omega}_{ib}^b = G_g \vec{f}_{ib}^b a$$

- G²-Sensitivity
 - Anisoelastic effects
 - Due to products of orthogonal forces

Inertial Sensors — Accel Specific Errors

- Axis Offset
 - The accel may be mounted at a lever-arm distance from the “center” of the Inertial Measurement Unit (IMU)
 - * Leads to an “ $\omega^2 r$ ” type effect

$$\Delta f_x = \omega_y^2 \Delta x + \omega_z^2 \Delta x = (\omega_y^2 + \omega_z^2) \Delta x$$



Inertial Sensors — Sensor Models

- Accelerometer model

$$\tilde{\vec{f}}_{ib}^b = \vec{f}_{ib}^b + \Delta\vec{f}_{ib}^b = \vec{b}_a + (\mathcal{I} + M_a)\vec{f}_{ib}^b + \vec{w}_a \tag{1}$$

- Gyro Model

$$\tilde{\vec{\omega}}_{ib}^b = \vec{\omega}_{ib}^b + \Delta\vec{\omega}_{ib}^b = \vec{b}_g + (\mathcal{I} + M_g)\vec{\omega}_{ib}^b + G_g \vec{f}_{ib}^b + \vec{w}_g \tag{2}$$

- Typically, each measures along a single sense axis requiring three of each to measure the 3-tuple vector