Lecture
Sensor Technology
EE 570: Location and Navigation

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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
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

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

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

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

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
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
    \[ \Delta f_z = m_{a,zz} f_z + m_{a,zy} f_y \]
    \[ \Delta \omega_z = m_{g,zz} \omega_z + m_{g,zy} \omega_y \]
- Combining misalignment & scale factor
  \[ \Delta \vec{f} = \begin{bmatrix} s_{a,x} & m_{a,xy} & m_{a,xz} \\ m_{a,yx} & s_{a,y} & m_{a,yz} \\ m_{a,zx} & m_{a,zy} & s_{a,z} \end{bmatrix} \begin{bmatrix} f_x \\ f_y \\ f_z \end{bmatrix} = M_a \vec{f}^b_{ib} \]

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

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 asymmetry
  – Mostly in Coriolis-based devices (MEMS)

\[
\Delta \omega^b_{ib} = G_g f^b_{ib} a
\]

• \(G^2\)-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 \(\omega^2r\) 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

\[
\tilde{f}^b_{ib} = f^b_{ib} + \Delta f^b_{ib} = \vec{b}_a + (I + M_a) \tilde{f}^b_{ib} + \vec{w}_a
\] (1)

• Gyro Model

\[
\tilde{\omega}^b_{ib} = \omega^b_{ib} + \Delta \tilde{\omega}^b_{ib} = \vec{b}_g + (I + M_g) \tilde{\omega}^b_{ib} + G_g \tilde{f}^b_{ib} + \vec{w}_g
\] (2)

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