# Lecture

## Sensor Technology

### EE 570: Location and Navigation

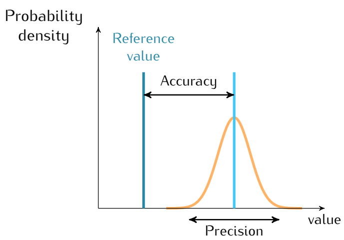
Lecture Notes Update on March 24, 2016

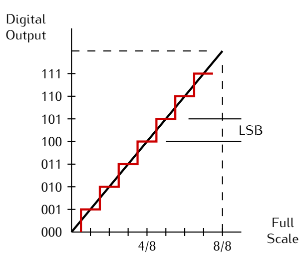
Aly El-Osery and Kevin Wedeward, Electrical Engineering Dept., New Mexico Tech
In collaboration with
Stephen Bruder, Electrical & Computer Engineering, Embry-Riddle Aeronautical University

.1

### Terminology

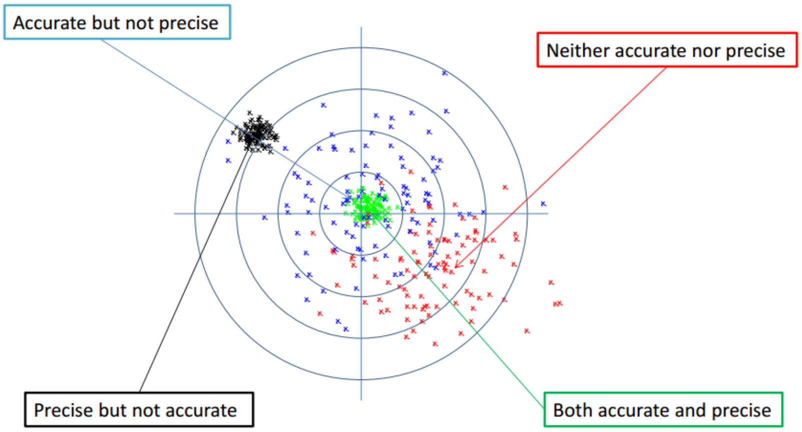
- **Accuracy:** Proximity of the measurement to the true value
- **Precision:** The consistency with which a measurement can be obtained
- **Resolution:** The magnitude of the smallest detectable change
- **Sensitivity:** The ratio between the change in the output signal to a small change in input physical 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




.2

## Accuracy vs Precision




.3

## 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**

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

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

.4

## Inertial Sensors — Scale Factor Errors

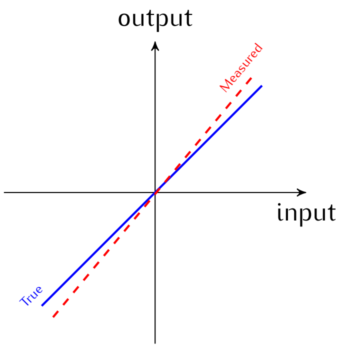
- Fixed scale factor error
  - Deterministic in nature and can be addressed by calibration
  - Often modeled as a function of temperature
- Scale Factor Stability $s_a$ (accel) or $s_g$ (gyro)
  - Varies from run-to-run as a random constant
  - Typically given in parts-per-million (ppm)

**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




.5

## Inertial Sensors — Misalignment

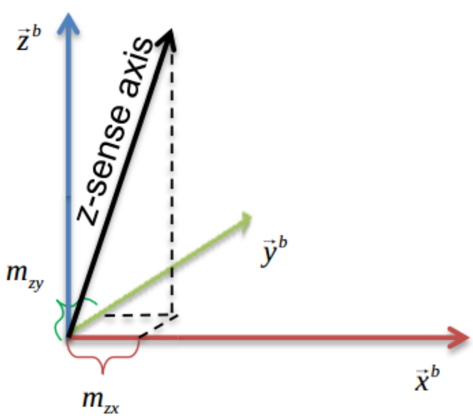
- Refers to the angular difference between the ideal sense axis alignment and true sense axis vector
  - a deterministic quantity typically given in milliradians

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

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

- Combining misalignment & scale factor

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




.6

## 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

.7

## Inertial Sensors — Other Noise Sources

Typically characterized as additive in nature

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

- Quantization noise
  * May be due to LSB resolution in ADC's
- Flicker noise
- Colored noise .8

## 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)

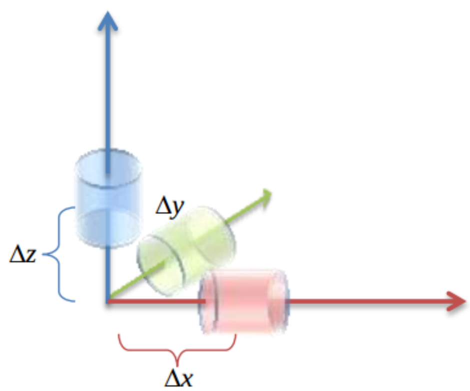
$$\Delta\vec{\omega}^{\,b}_{ib} = G_g \vec{f}^{\,b}_{ib} a$$

- $G^2$-Sensitivity
  - Anisoelastic effects
  - Due to products of orthogonal forces .9

## 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

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




.10

## Inertial Sensors — Sensor Models

- Accelerometer model

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

- Gyro Model

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

- Typically, each measures along a signle sense axis requiring three of each to measure the 3-tupple vector .11