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College of Engineering and Petroleum

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ME319 MECHATRONICS

Part III: The Senses – Sensors and Signals

Lecture 4: Motion Sensors

Spring 2021

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Objectives

- Introduction to the Motion MEMS and environmental sensor expansion board (X-NUCLEO-IKS01A2)
- Know what MEMS are and how they work
- Understand the basic operation of an IMU

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X-NUCLEO-IKS01A2 Expansion Board

- It's an add-on board with multiple sensors installed
- Specifically, 4 Sensor ICs:
  1. A temperature and relative humidity sensor (HTS221)
  2. A pressure sensors (LPS22HB)
  3. A 3D Accelerometer and 3D Gyroscope (LSM6DSL)
  4. A 3D Accelerometer and 3D Magnetometer (LSM303AGR)
- Yes there are two sensors that give accelerometer data.
  - Can pick just one source of accelerometer
  - Or use two for averaging?

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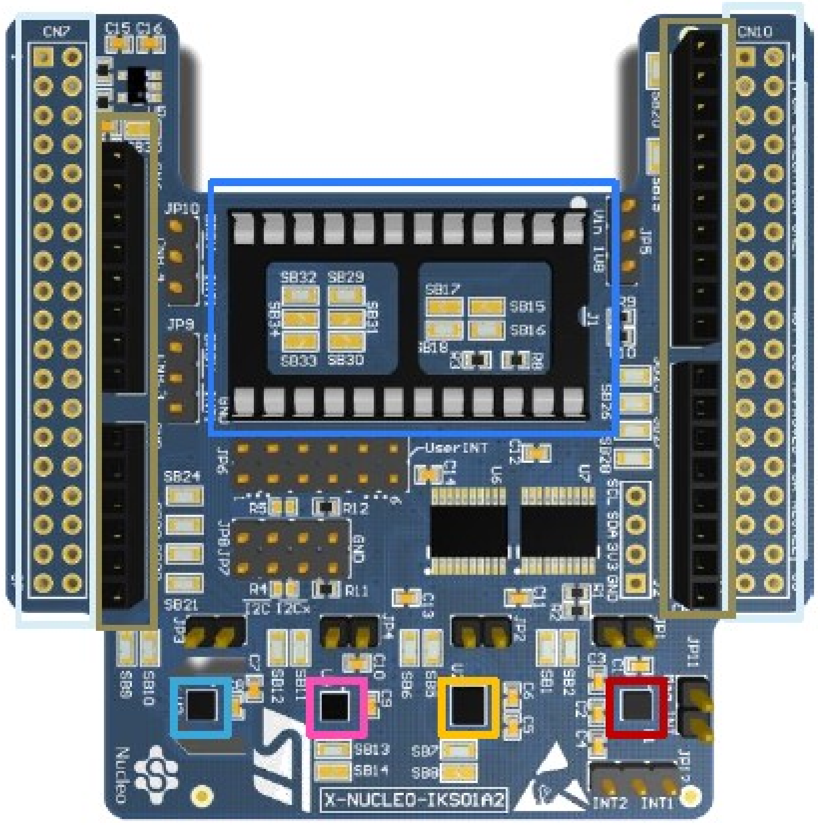
X-NUCLEO-IKS01A2



- HTS221
- LPS22HB
- LSM6DSL
- LSM303AGR
- ST morpho connector**
- Arduino UNO R3 connector
- DIL 24-pin

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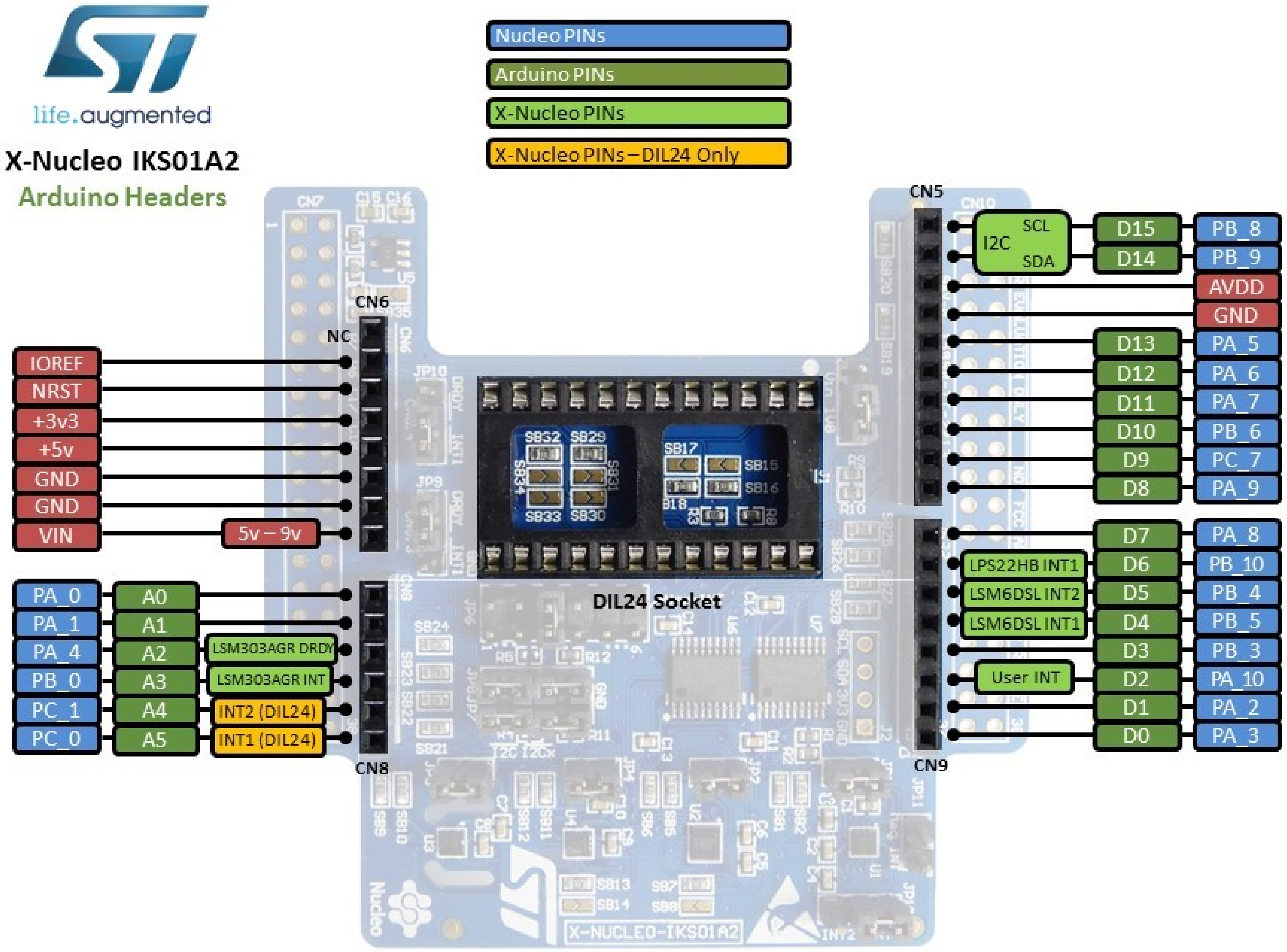
life.augmented
X-Nucleo IKS01A2
Arduino Headers
Nucleo PINs
Arduino PINs
X-Nucleo PINs
X-Nucleo PINs – DIL24 Only
CN6
NC
IOREF
NRST
+3v3
+5v
GND
GND
VIN
5v – 9v
PA_0
PA_1
PA_4
PB_0
PC_1
PC_0
A0
A1
A2
A3
A4
A5
LSM303AGR DRDY
LSM303AGR INT
INT2 (DIL24)
INT1 (DIL24)
CN8
DIL24 Socket
CN5
I2C
SCL
SDA
D15
D14
PB_8
PB_9
AVDD
GND
D13
D12
D11
D10
D9
D8
PA_5
PA_6
PA_7
PB_6
PC_7
PA_9
D7
D6
D5
D4
D3
D2
D1
D0
LPS22HB INT1
LSM6DSL INT2
LSM6DSL INT1
User INT
PA_8
PB_10
PB_4
PB_5
PB_3
PA_10
PA_2
PA_3
CN9
X-NUCLEO-IKS01A2

Accelerometer

- Device that measure static and dynamic forces
- Used to measure
  - Orientation
  - Inertial measurement of velocity and position
  - Vibration or impact

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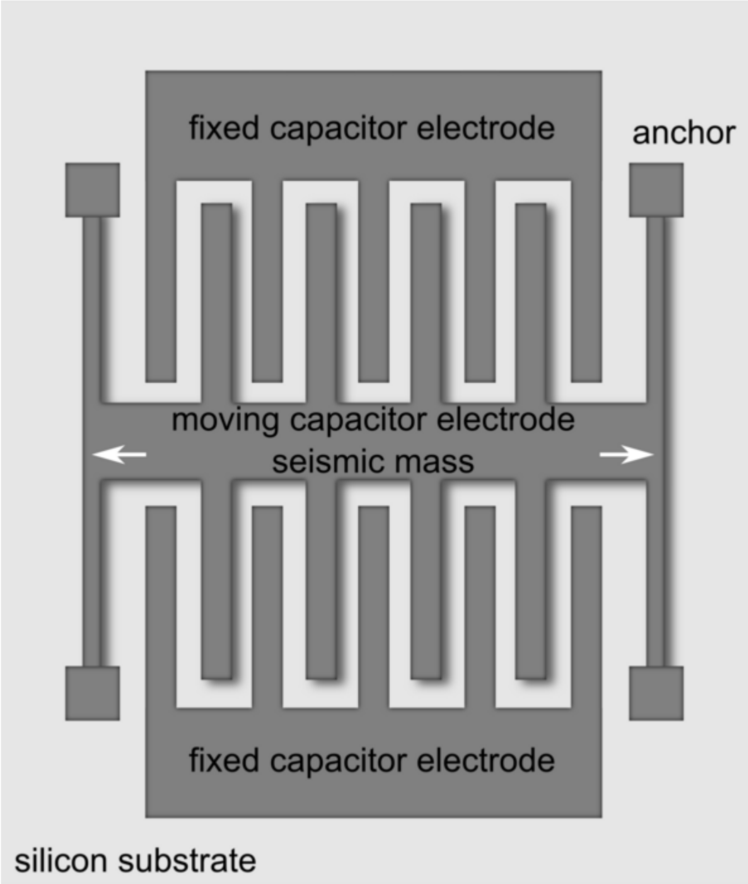
- Many different accelerometer types
  - Piezoresistive
  - Hall Effect
  - Heat Transfer
  - Optical
  - Servo Force Balance
  - MEMS
- We are using a Microelectromechanical Sensor



Accelerometer Characteristics

- Bandwidth:
  - Readings per second
- Sensitivity:
  - Signal amplitude as result of change in acceleration
- Analog/Digital
  - Analog: direct analog output
  - Digital: ADC on MEMS chip
    - Communication Protocol
    - ADC resolution/range
- Dynamic Range

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Accelerometer on both LSM6DSL and LSM303AGR

- 3 Axis separate proof mass MEMs
- Acceleration in one axis induces displacement of mass and capacitive sensors detect differential displacement
- Sitting still, axis collinear to earth gravity will output 1g and 0g on the other two orthogonal axes
- Used as inclinometer (measure title angle, e.g. detect phone in landscape)
- Programmable range
  - ±2g, ±4g, ±8g or ±16g

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Accelerometer Orientation

Figure 1. Pin connections

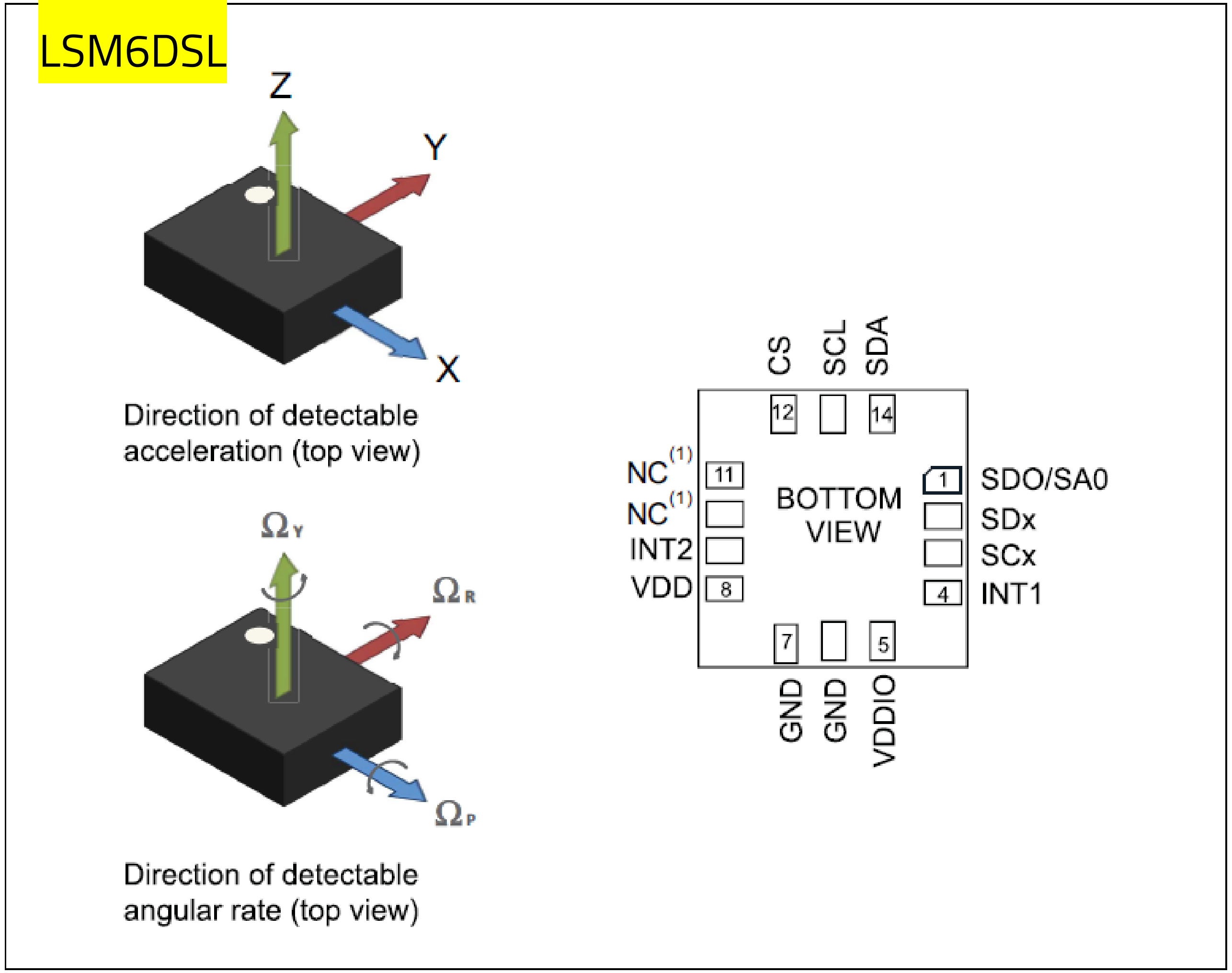
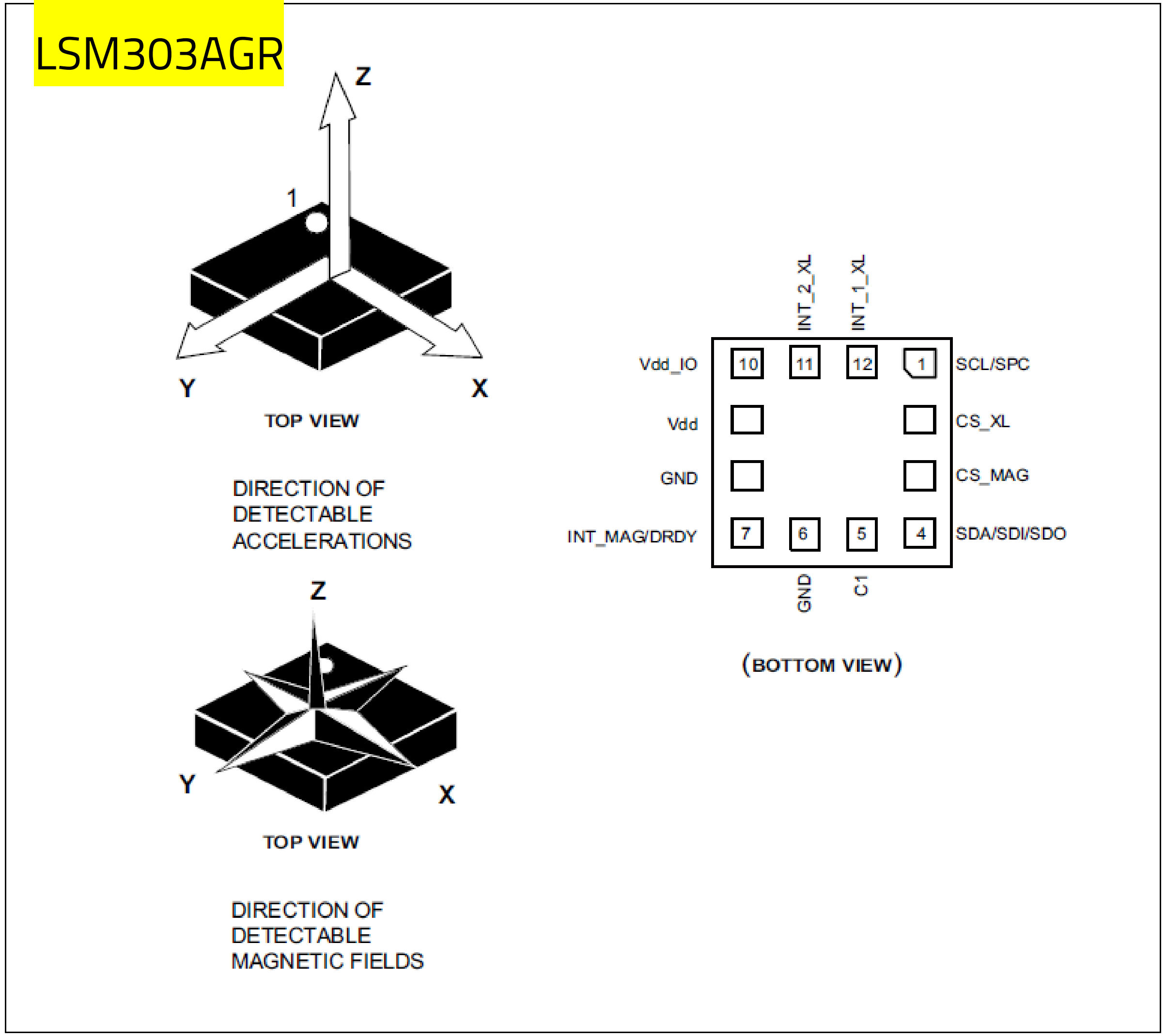


Figure 2. Pin connections



Gyroscope

- Device that measure rotation
- Different technologies
  - MEMs
  - FOG: Fiber Optic Gyroscope
  - HRG: Hemispherical Resonator Gyroscope
  - VSG: Vibrating Structure Gyroscope
  - DTG: Dynamically Tuned Gyroscope
  - RLG: Ring Laser Gyroscope (Highly Accurate)

Gyroscope invented by Léon Foucault in 1852 (Replica)

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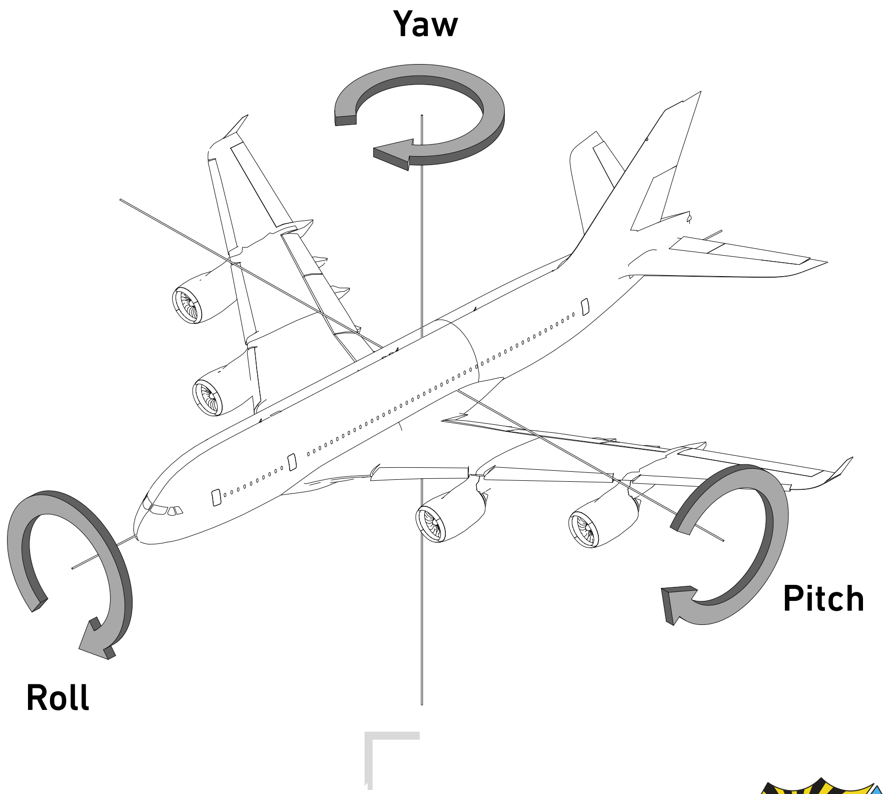
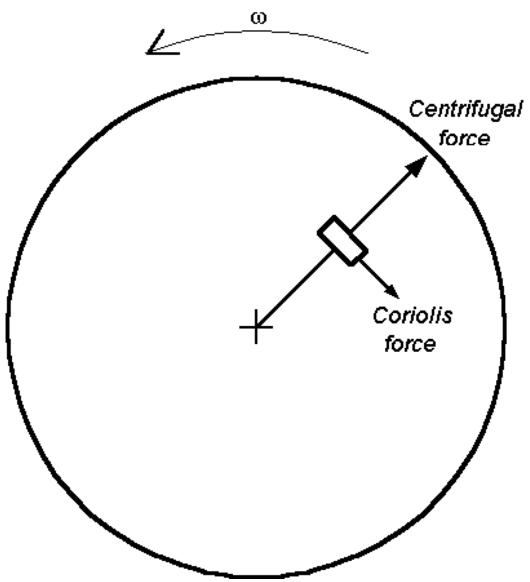
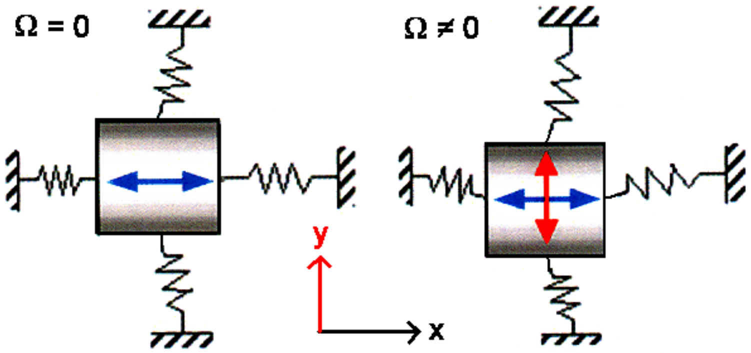
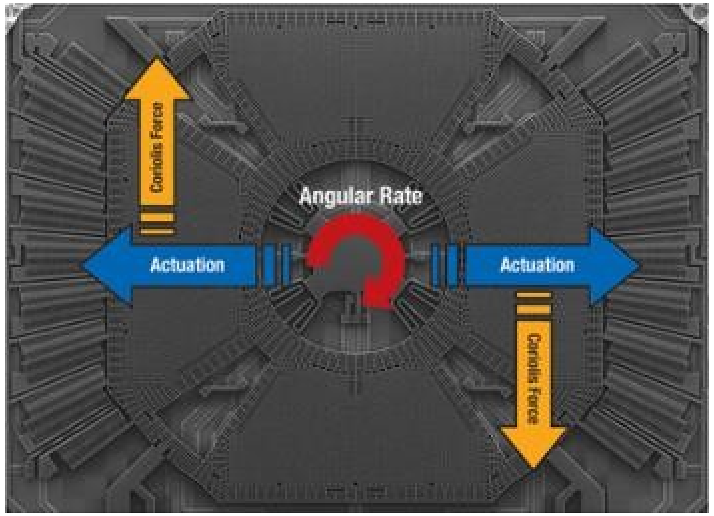
- 3 Axis vibratory MEMs rate gyroscope
- When rotated, Coriolis effect causes a vibration that is detected by a capacitive pickoff
- Output in deg/s or mdeg/s
- Programmable Range
  - ±125 , ±250, ±500, ±1000 or ±2000 deg/s

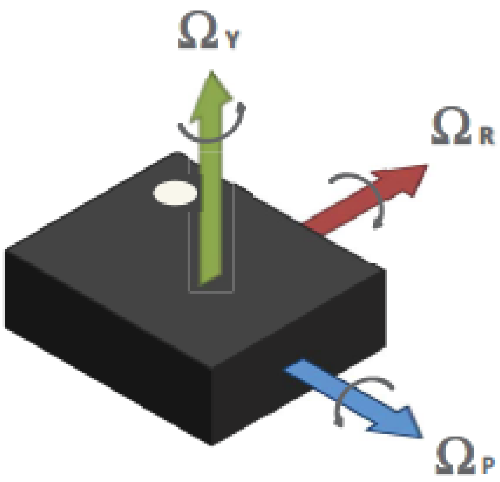


- MEMS Gyros based on vibratory sensors
  - Vibrating objects undergoing rotations
  - Coriolis force orthogonal to vibrating object
  - $\vec{a}_B = \vec{a}_A + \vec{\alpha} \times \vec{r}_{B/A} + \vec{\omega} \times (\vec{\omega} \times \vec{r}_{B/A}) + \mathbf{2\vec{\omega} \times (\vec{v}_{B/A})_{xyz}} + (\vec{a}_{B/A})_{xyz}$

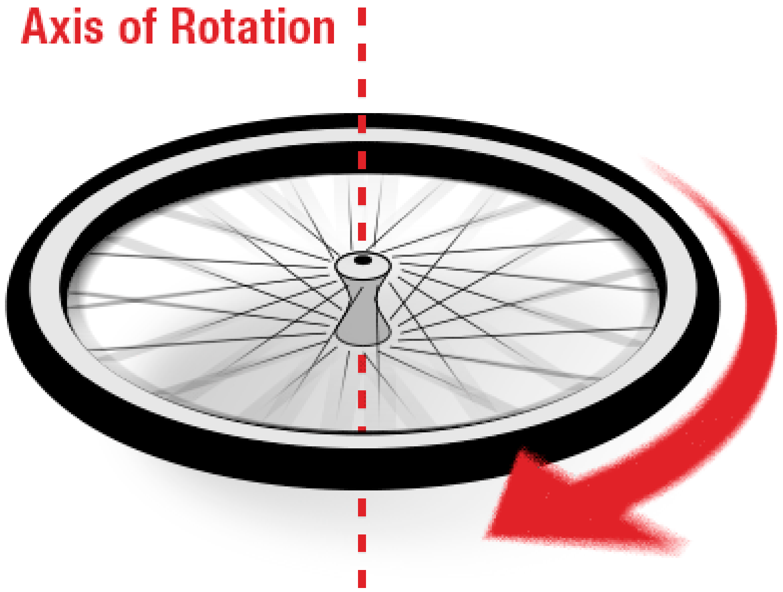








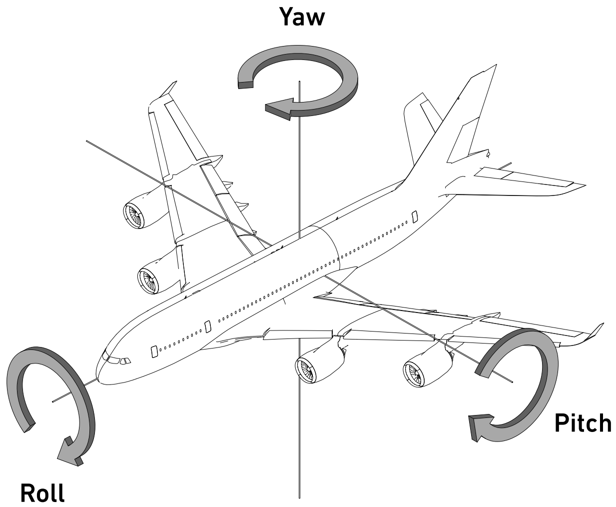
Direction of detectable angular rate (top view)



$$Gyro = \{0,0,-X\}$$

Gyro Drift (Bias or variation)

- Gyro readings drift over time
  - Due primarily to internal temperature changes
- Drift effect is cumulative
- To correct for drift
  - Zero measurements when sensor is stationary
  - Measure drift over time while stationary and use information to correct for drift continuously
  - Gyros may have a temperature sensor that can be used to correct for drift as well
- In practice, a combination of these correction methods is used



Magnetometer

- Device that measures strength of a magnetic field
- Used in
  - Object detection
  - Mining
  - Weather prediction
  - Heading
- Different technologies
  - Inductive Pickup Coils
  - VSM: Vibrating Sample Magnetometer
  - Pulsed Field Extraction Magnetometry
  - Optical Magnetometry
  - Hall Effect Magnetometer
  - Fluxgate Magnetometer
  - And other types

Magnetometer on LSM303AGR

- 3 Axis magnetometer using highly sensitive Hall sensor
- Output magnetic field strength in mGauss (microGauss)
  - Also measured in Tesla sometimes: 1 Tesla = 10,000 Gauss
- Full range of ±50Gauss
- Measures Magnetic North
  - To measure true north, must account for inclination and declination.
  - Magnetic Declination: Angle between magnetic north and true north. Changes with location and time
  - Magnetic Inclination: Measure of vertical intensity of earth’s magnetic field. Changes with location (Latitude)
- Accelerometers are used with magnetometers to perform tilt compensation
  - If sensor’s compass axis is titled

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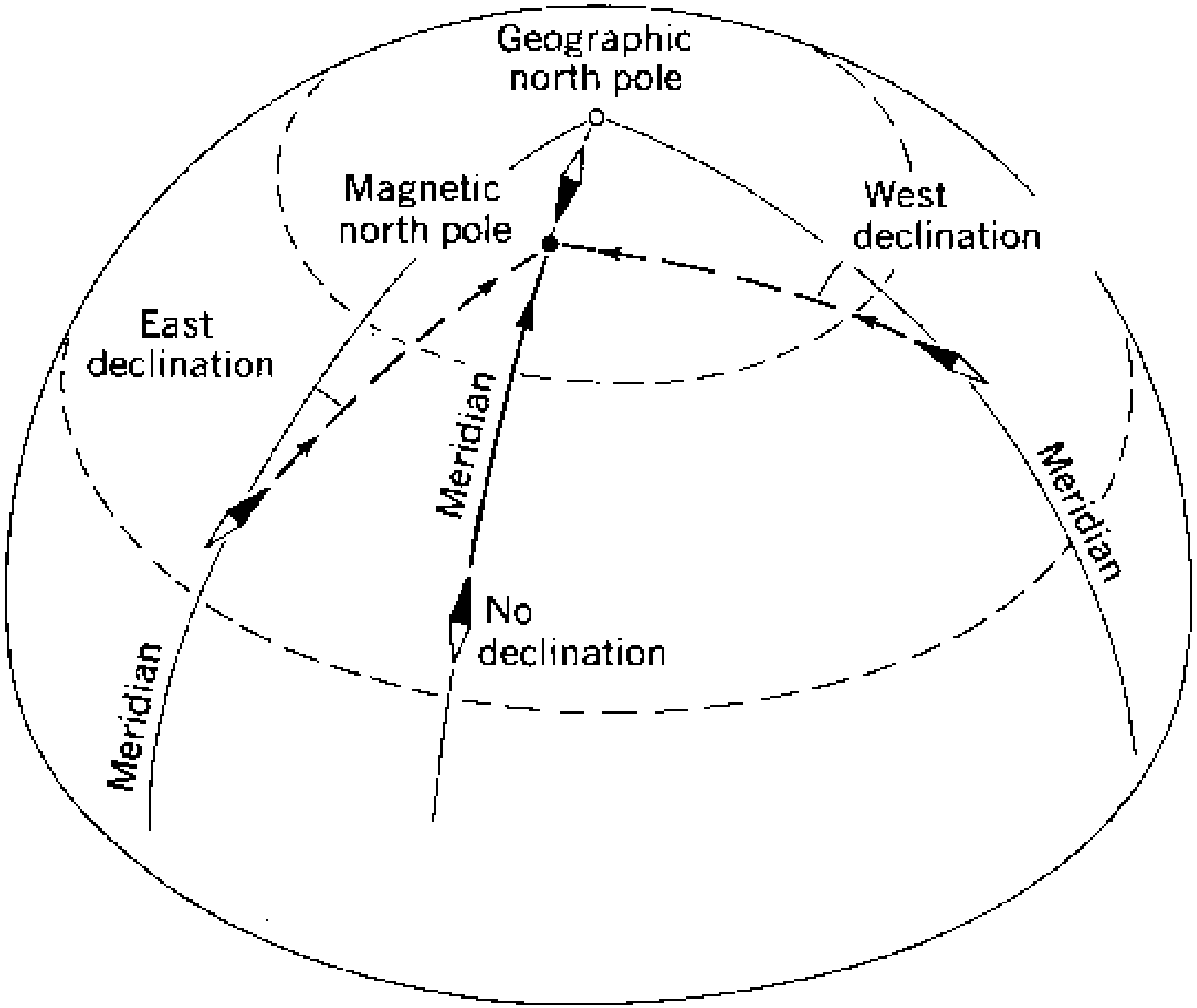
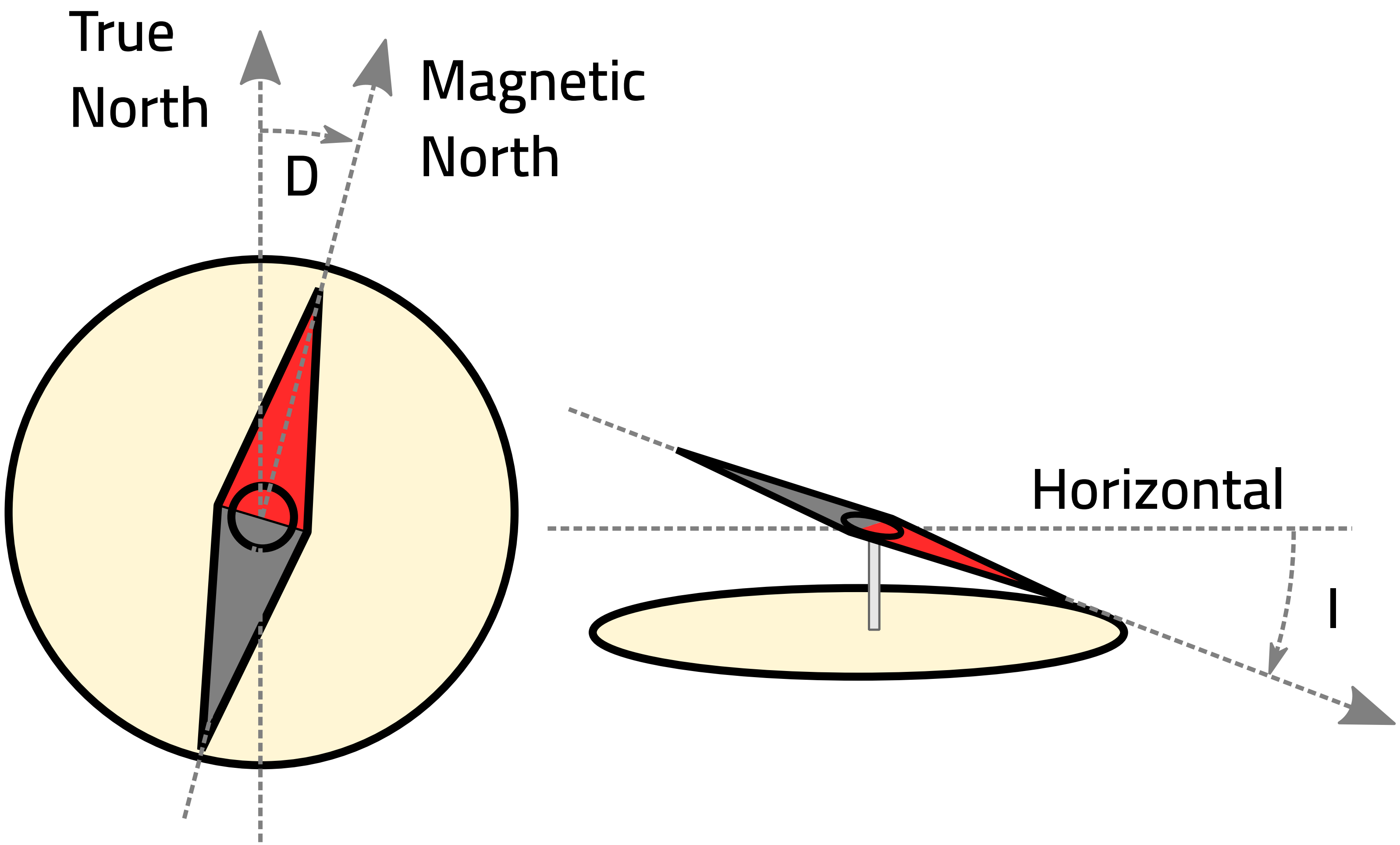
- Location and time dependent



- Location dependent

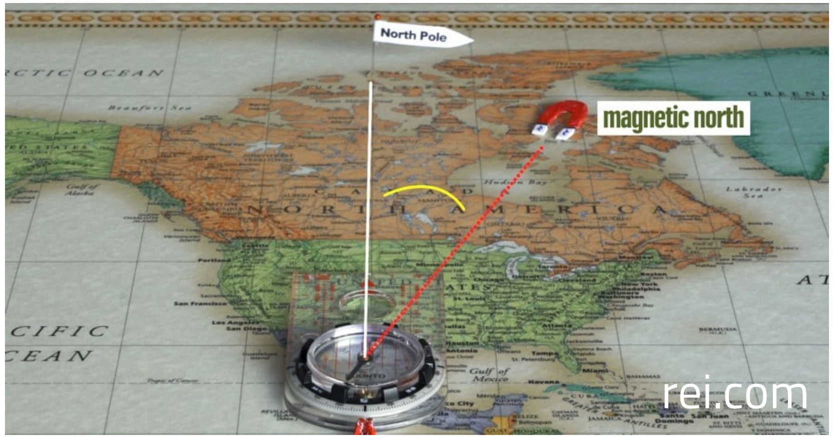


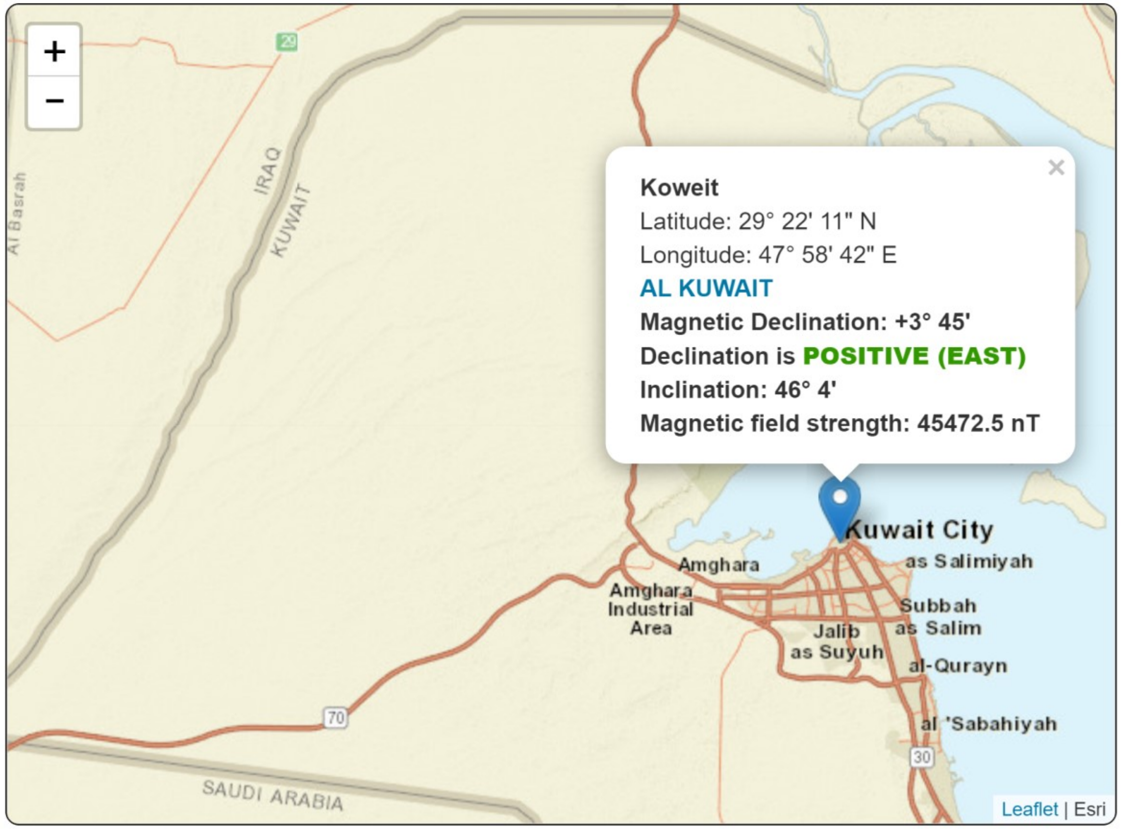
Declination

Inclination

Magnetic North vs True North

- Magnetic North
  - North as given by the sensor
  - The direction of the earth's magnetic field
- True North
  - The direction along the meridian toward the geographic north pole
  - We take magnetic north, compensate for inclination and declination to get true north.





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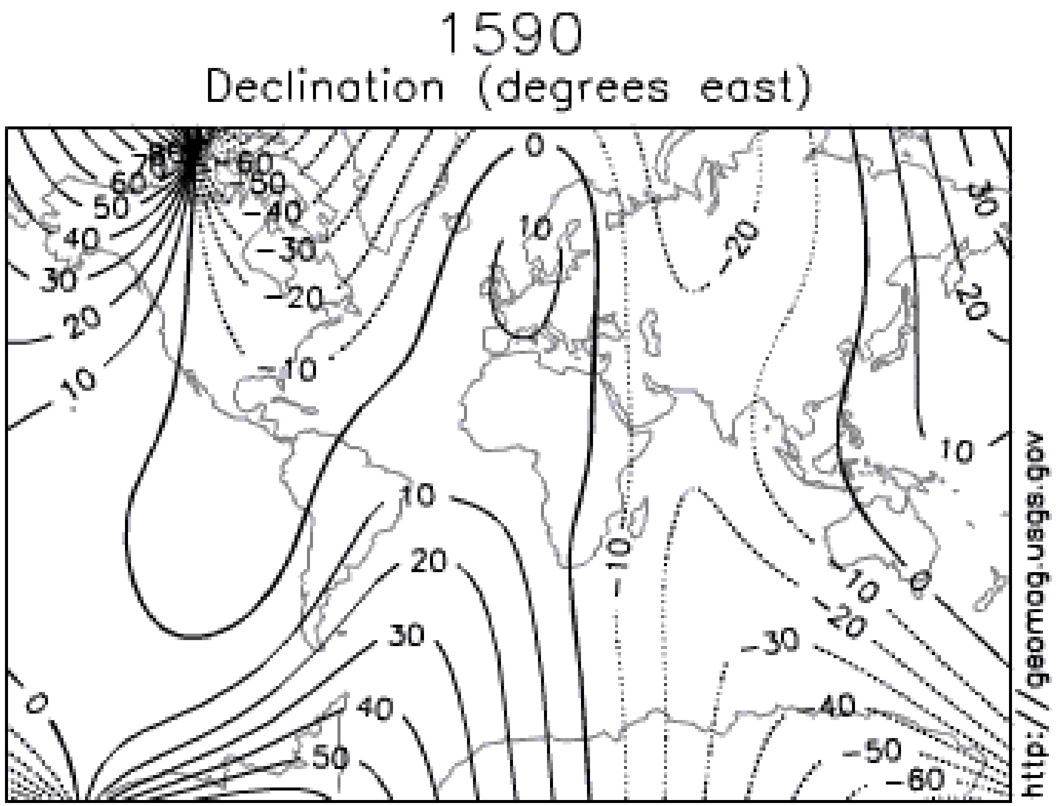
- Declination Changes with time as well as geographic location



Model by A. Jackson, A. R. T. Jonkers, M. R. Walker, Phil. Trans. R. Soc. London A (2000), 358, 957–990.

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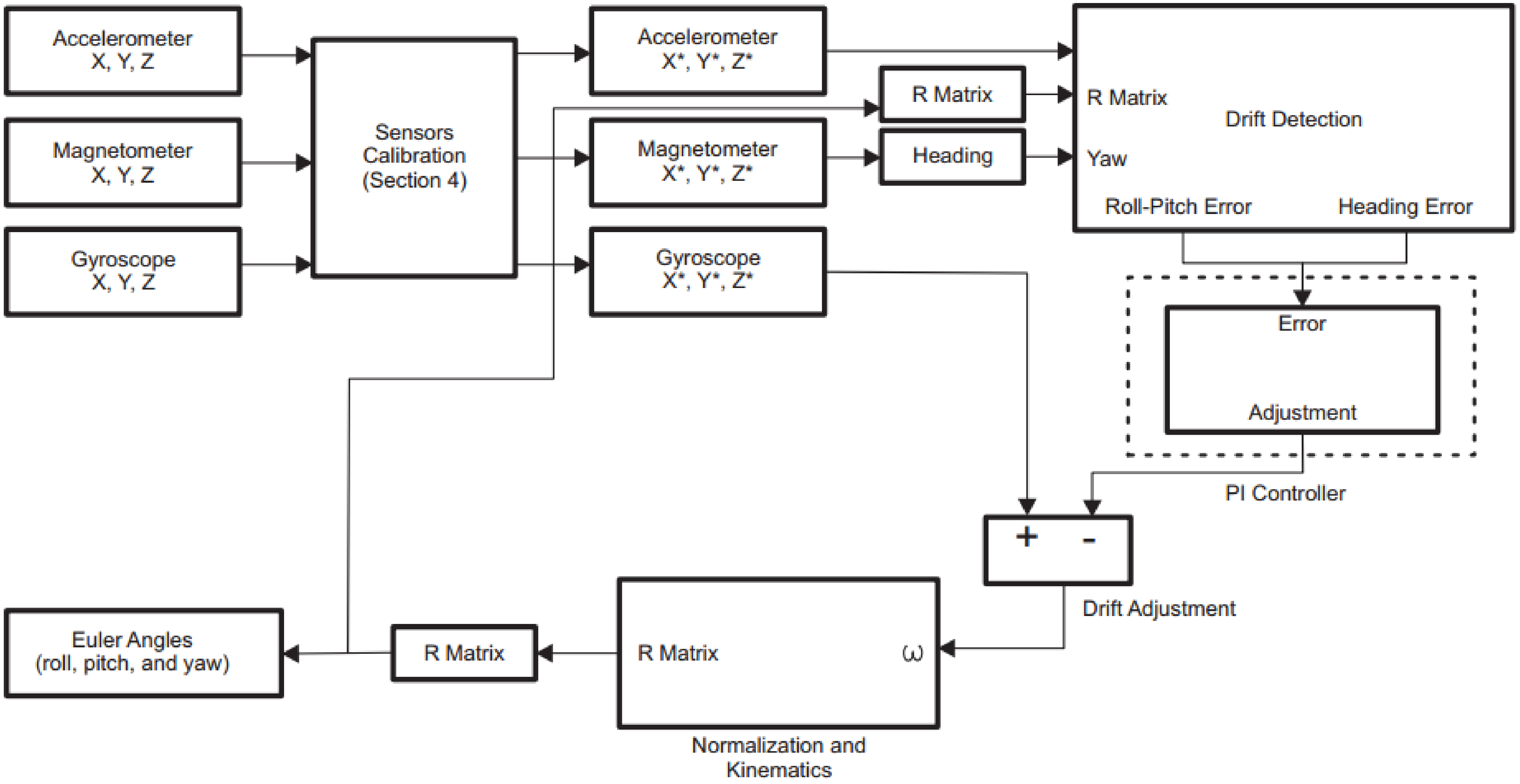
IMU

- IMU: Inertial Measurement Unit
- ACC + GRYO = 6DOF IMU
- ACC + GYRO + MAG = 9DOF IMU

- Math, System Dynamics & Control



IMU Calibration

- Gyroscope
  - Calibrate against drift
  - Usually done by zeroing drift while sensor is still
- Accelerometer
  - Calibrate against offset
  - Done by placing sensor still at 6 different cube faces
- Magnetometer
  - Calibrate against extent and strength of magnetic filed
  - Usually done by rotating the sensor around 3 axis in both directions (6 rotations)
- Some sensors have onboard calibration routines
- Others require calibration to be done at software

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Pressure Sensor

- Peizoresistive Pressure Sensor
- Used for
  - Altitude measurement
    - Navigation Aid
  - Weather forecast
  - Vertical Velocity

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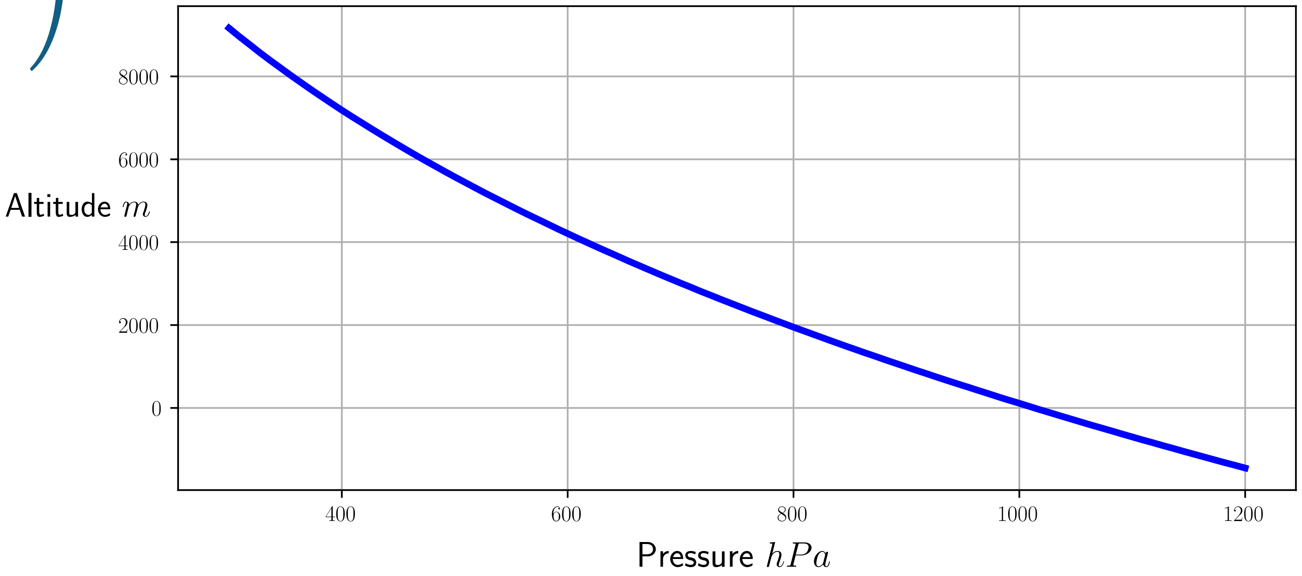
- Outputs absolute pressure in hPa (hectopascal). $1\ hPa = 100Pa$
- Altitude Above Sea Level

$$altitude = 44330\left(1 - \left(\frac{p}{p_o}\right)^{\frac{1}{5.255}}\right)$$



- Pressure at Sea Level

$$p_o = \frac{p}{\left(1 - \frac{altitude}{44330}\right)^{5.255}}$$

- Sea Level Standard Atmospheric Pressure

$$p_o = 1013.25hPa$$

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