UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha

HITLabNZ
Human Interface Technology Lab New Zealand
Hangarau Tangata, Tangata Hangarau
www.hitlabnz.org

Application of Inertial Measurement Unit For Humanoid Robot Stability

by

Humayun Khan

UC Product Design

UC ENGINEERING
Te Rāngai Pūkaha

UC COMPUTER SCIENCE & SOFTWARE ENGINEERING

Who we are?

- Electric Sheep
- OpenSource platfrom: https://github.com/electric-sheep-uc
- Team members:
  - University of Canterbury
  - Industry

Outline

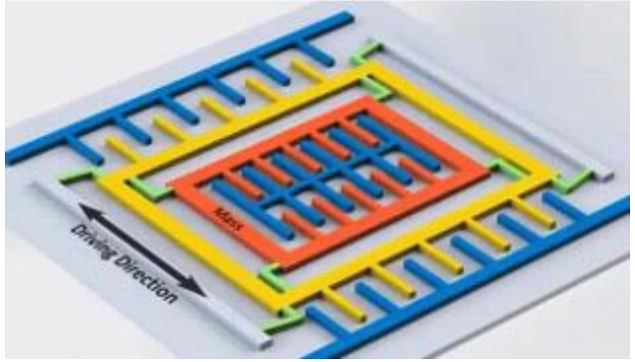
- Introduction
- IMU Components
- Noise and Sensor bias
  - Grades of IMU
  - MEMs-based IMU used for RoboCup
- Raw IMU data to roll and pitch angle
- Case for Stability

Inertial Measurement Unit (IMU)

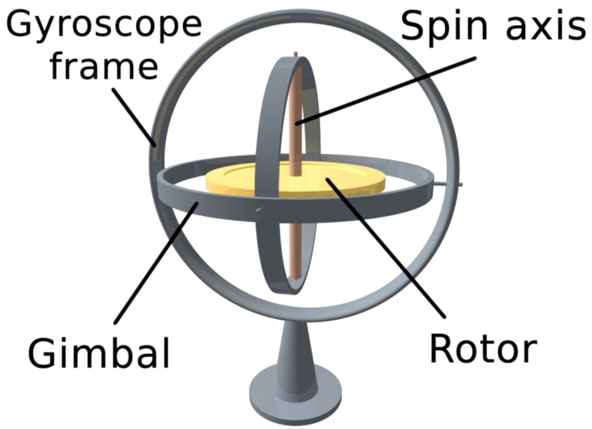
- A device that measures the acceleration and angular velocity of the body
- Applications:
  - Dead reckoning
  - Attitude and heading reference system
  - Inertial navigation
  - Robot stability

IMU components – Gyroscope

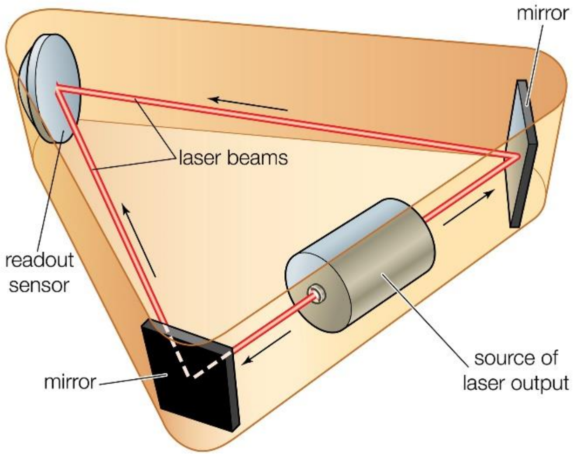
- Gyroscope, rad/s
  - MEMS-based,
  - Mechanical
  - Optical



[1] https://howtomechatronics.com



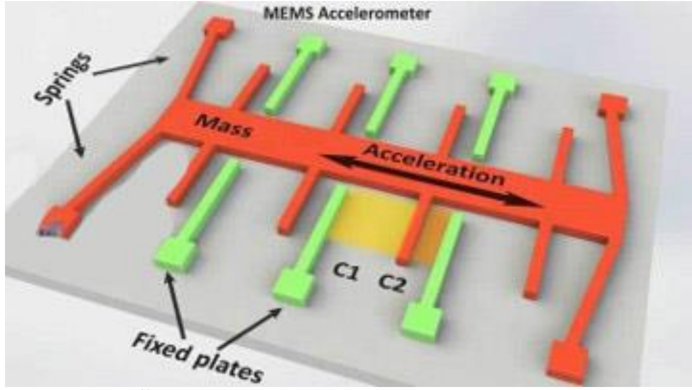
[2] https://en.wikipedia.org/wiki/Gyroscope



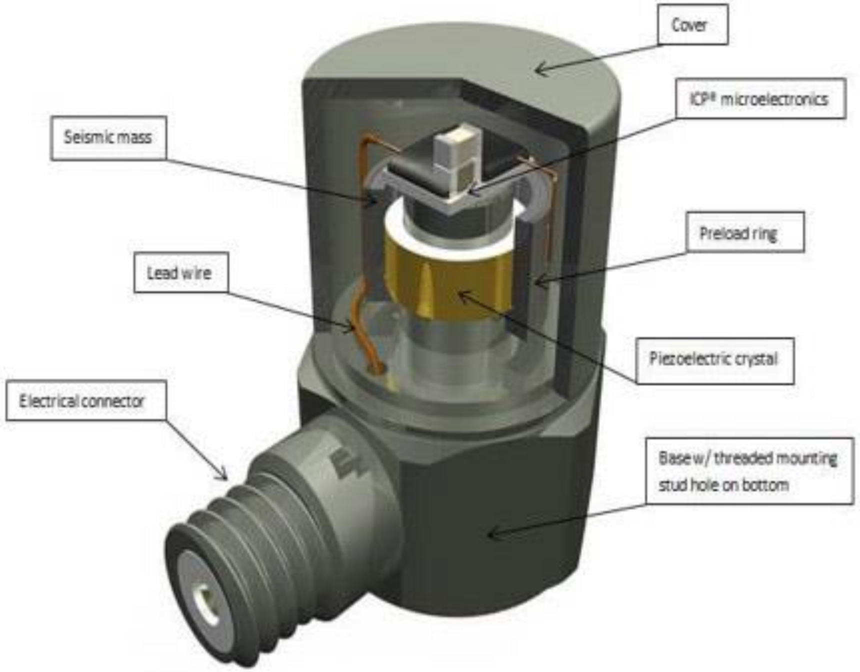
[3] https://www.britannica.com/technology/ring-laser-gyroscope

IMU components – Accelerometer

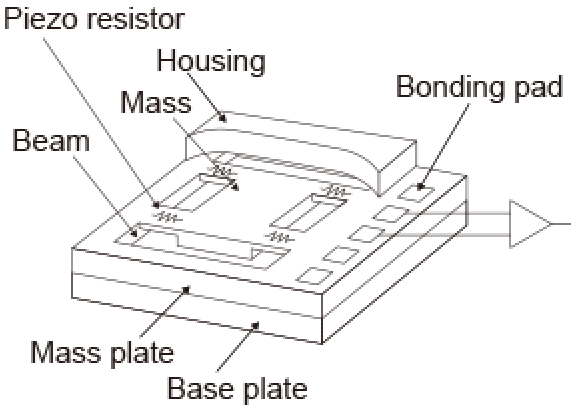
- Accelerometer Type, m/s^2
  - MEMS-based
  - Piezo-electric
  - Piezo-resistive



[4] https://howtomechatronics.com



[5] https://www.pcb.com/resources/technical-information/introduction-to-accelerometers



[6] https://www.imv.co.jp/e/products/vibrograph/pickup/piezo/

Noise, Bias, and Scale Factor

- Measured accelerometer value, a_m

  $a_m = M_a(S_a(a - a_{gravity}) - \beta_a(T))$

  M_a = Accelerometer misalignment matrix

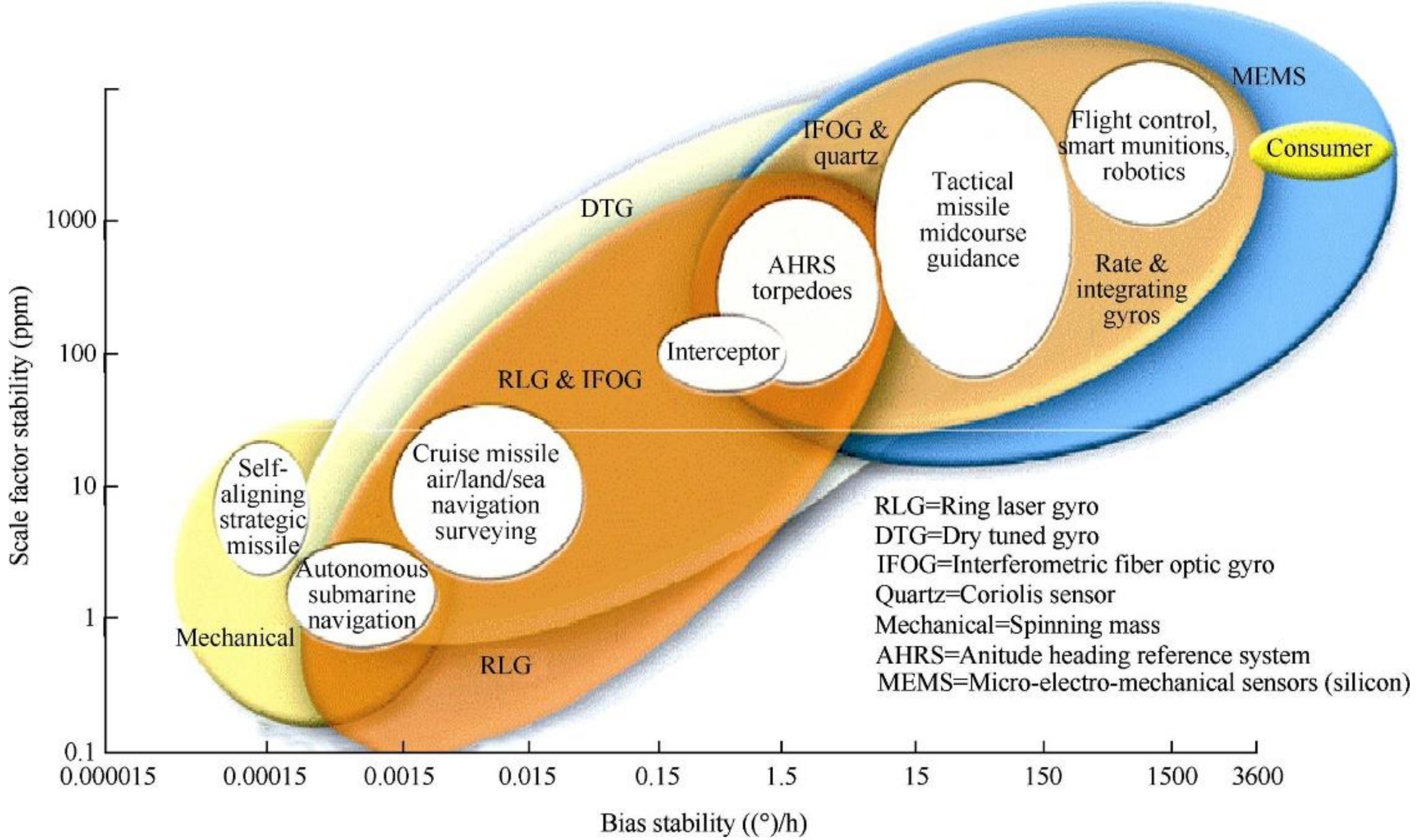
  $\beta_a(T)$ = Temperature varying biases

  $$S_a = \begin{pmatrix} S_{ax} & 0 & 0 \\ 0 & S_{ay} & 0 \\ 0 & 0 & S_{az} \end{pmatrix}$$

- Measured Gyro value, $\omega_m = M_g((S_g\ \omega_a) - \beta_g(T))$

Grades of IMUs - Gyroscope

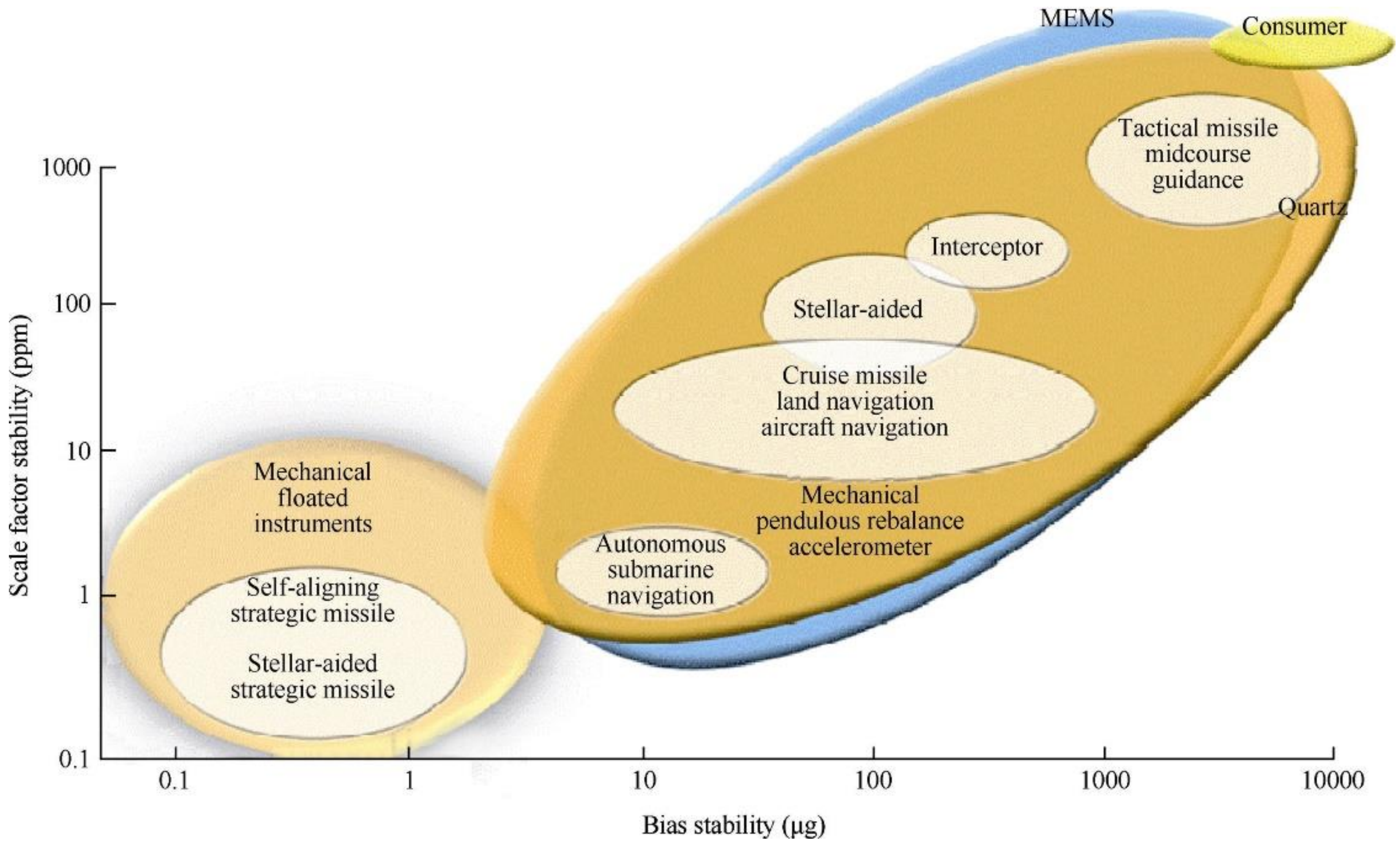
- Marine Grade
- Tactical Grade
- Industrial Grade
- Consumer Grade



[7] Schmidt GT. Navigation sensors and systems in GNSS degraded and denied environments. Chinese Journal of Aeronautics. 2015 Feb 1;28(1):1-0.

Grades of IMUs – Accelerometer

- Marine Grade
- Tactical Grade
- Industrial Grade
- Consumer Grade

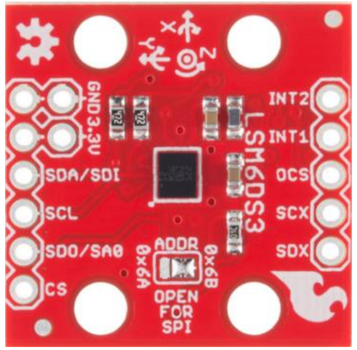


[7] Schmidt GT. Navigation sensors and systems in GNSS degraded and denied environments. Chinese Journal of Aeronautics. 2015 Feb 1;28(1):1-0.

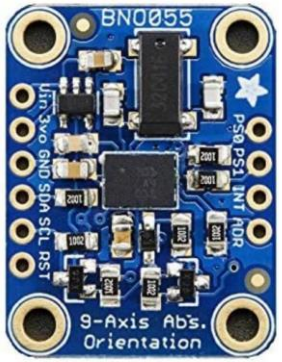
MEMS IMU Vendors

- Consumer Grade
  - TDK Invensense
  - STMicroelectronics
  - Bosch
- Industrial Grade
  - XSens, Analog Devices
  - VectorNav, Thales

[8] https://invensense.tdk.com



[9] https://www.st.com



[10] https://www.bosch-sensortec.com

[12] https://www.xsens.com/

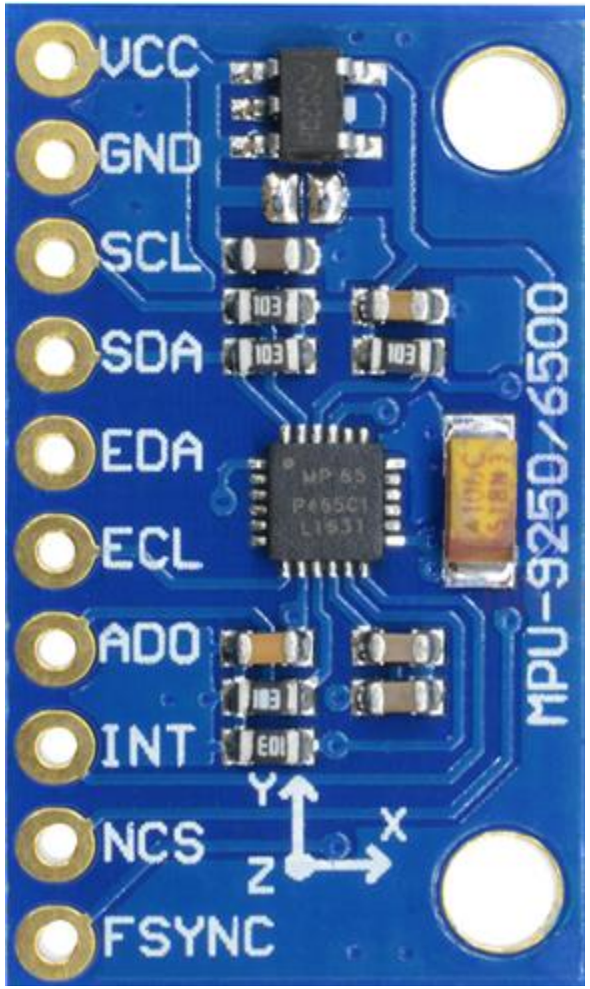

[13] https://www.vectornav.com/

Example: TDK Invensense MPU6500

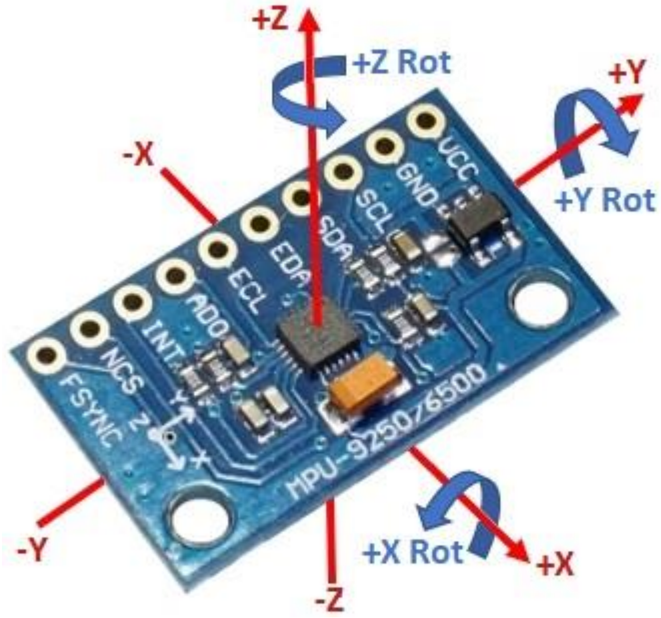
- Hardware Specification:
  - Gyro modes: ±250, ±500, ±1000, ±2000 ° /sec
    Accelerometer Modes: ±2g, ±4g, ±8g, ±16 g
  - Sampling frequency: 0.24 Hz to 500 Hz
  - Hardware connection via I2C bus
- Connect to Arduino, Raspberry Pi, or any microprocessor with I2C bus

Setting up the MPU6500

Voltage, Vcc 3.3 V
Ground
I2C Clock
I2C Data
External SPI Data
External SPI Clock
I2C Address Select
Interrupt
SPI Chip Select
Frame Synchronisation



Raw Data and Reference frame



COM13

	X	Y	Z
Accel:	0.211	6.685	-70.661
Gyro:	-0.004	0.020	0.009
Mag:	0.000	0.000	0.000
Temp:	22.614		
	Angle in Degrees		
Pitch:	0.170173		
Roll:	5.407133		

Accelerometer, Computing Euler angles

- Accelerometer: a_x, a_y, a_z , IMU with g in z-axis

$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos(-\theta_x) & -\sin(-\theta_x) \\ 0 & \sin(-\theta_x) & \cos(-\theta_x) \end{pmatrix} \begin{pmatrix} \cos(-\theta_y) & 0 & \sin(-\theta_y) \\ 0 & 1 & 0 \\ -\sin(-\theta_y) & \sin(-\theta_x) & \cos(-\theta_y) \end{pmatrix} \begin{pmatrix} \cos(-\theta_z) & -\sin(-\theta_z) & 0 \\ \sin(-\theta_z) & \cos(-\theta_z) & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$$

Roll, $\Phi_{xyz} = \tan^{-1}\left(\frac{a_y}{a_z}\right)$

Pitch, $\theta_{xyz} = \tan^{-1}\left(\frac{-a_x}{(a_y^2+a_z^2)^{-0.5}}\right)$

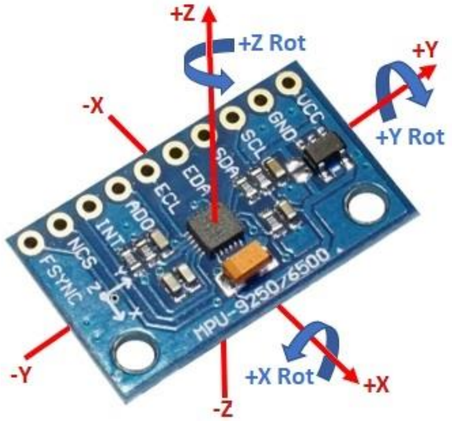
Gyroscope, Computing Euler angles

- Gyroscope: $\omega_x , \omega_y , \omega_z$ and Δt

  Initial Orientation: i_x, i_y

  Roll, $\Phi = i_x + \omega_x \times \Delta t$

  Pitch, $\theta = i_y + \omega_y \times \Delta t$



Sensor Fusion

- Complementary Filter
  - Fixed ratio
  - Accelerometer and Gyroscope
    - Pitch and Roll angles
- Kalman Filter
  - Change in weights based on computed covariance
  - Adaptable to dynamic changes

Robot Stability

- Suggestions for humanoid robot torso stability
  - Mounting IMU near to the center of mass
  - Orientation of the IMU
  - Sensing change is torso pitch and roll angle
  - Keeping a high sampling frequency
  - Non-linear control system

Conclusion

- ❑ Effect of temperature
- ❑ Removal of sensor biases
- ❑ Choice of sensor for humanoid robots
- ❑ Sensor fusion approaches
- ❑ Using Roll and Pitch to stabilise the robot

Questions