Topics in Autonomous Navigation

IRON REIGN

WWW.IRONREIGNROBOTICS.COM

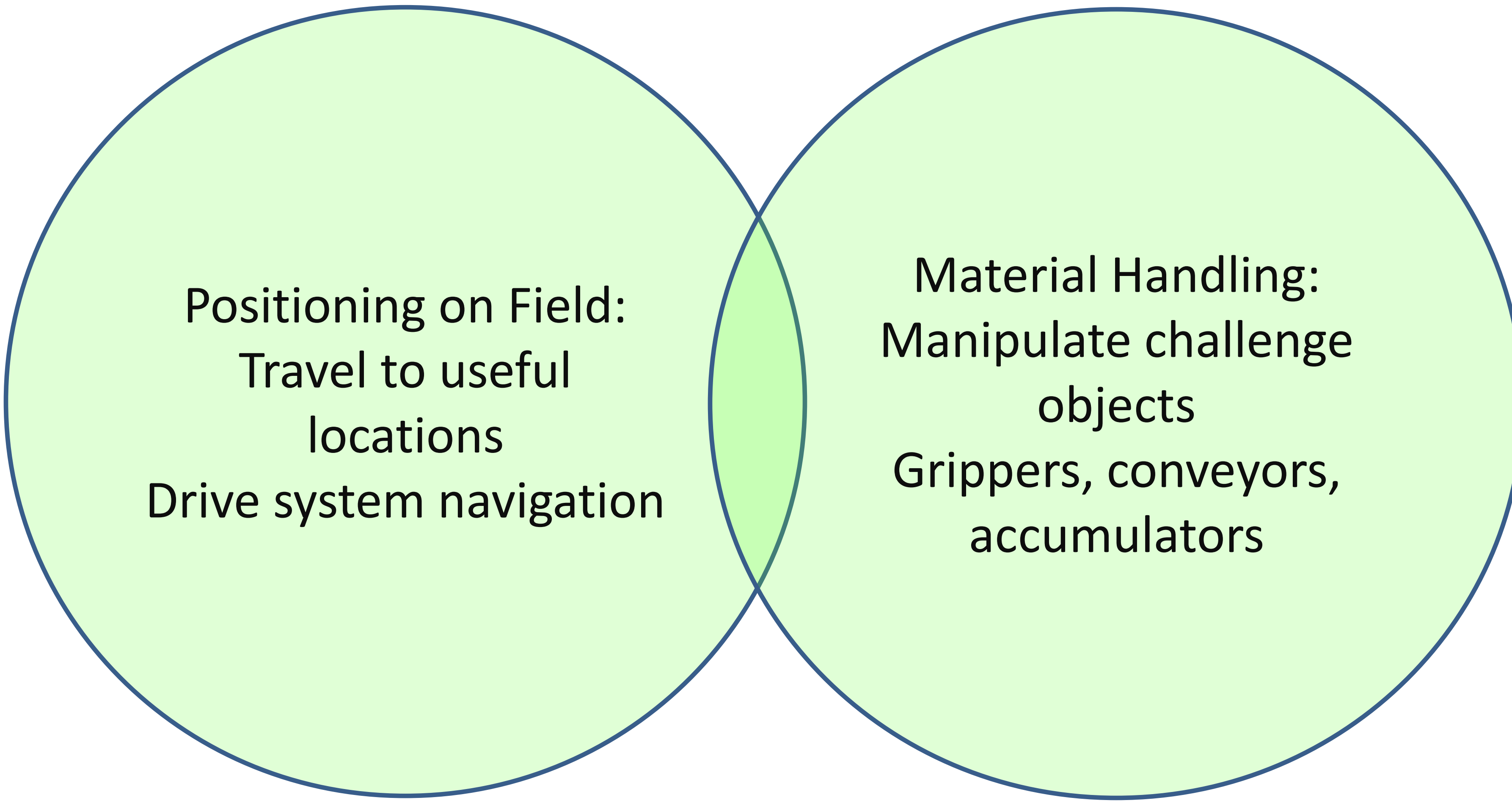
FTC Team #6832

Science and Engineering Magnet - Dallas ISD

Why Autonomous?

- Teams with autonomous have a real competitive advantage
  - Increased point ceiling – simple math
  - Technical judging favors autonomous capability
  - More attractive to other teams during alliance selection
  - Expect all championship teams will have autonomous
- It’s more interesting for college level work

What your robot Does



What your robot Does

TELE-OP

AUTONOMOUS

Positioning on Field:
Travel to useful locations
Drive system navigation

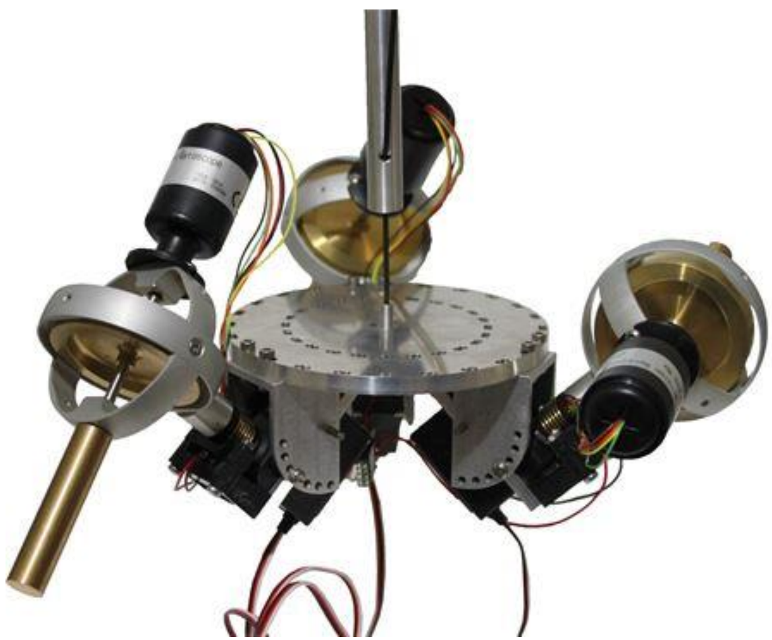
Material Handling:
Manipulate challenge objects
Grippers, conveyors, accumulators

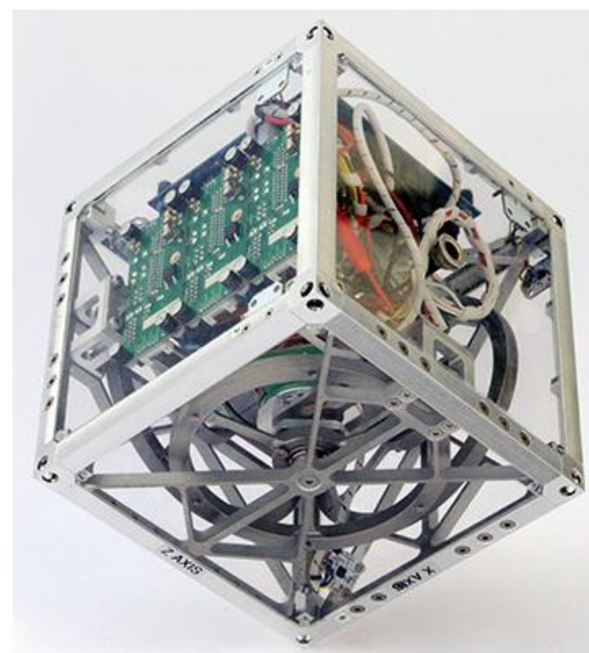
Autonomous Navigation Competencies

- Make some part of your robot move
- Drive forward a known distance
  - Drive for a given time at given voltage
  - Drive for a given number of motor encoder ticks
- Drive straight until a different sensor (proximity) triggers a stop behavior
- Turn to a given relative heading using odometry
- Turn to a given relative heading using a gyro or IMU
- Follow a line or beacon or heading (or color)
- Chain together a series of go straight, turn, follow and stop behaviors
- Add PID control to your following routines
- Waypoint navigation – set a series of waypoints in a Cartesian grid and the robot calculates the correct series of move using trig
- Dynamic collision avoidance
- Add curves to your bag of tricks
- Integrate 3 DOF movement if you have a holonomic platform

Gyro Types - Mechanical

Hubble Gyro Unit





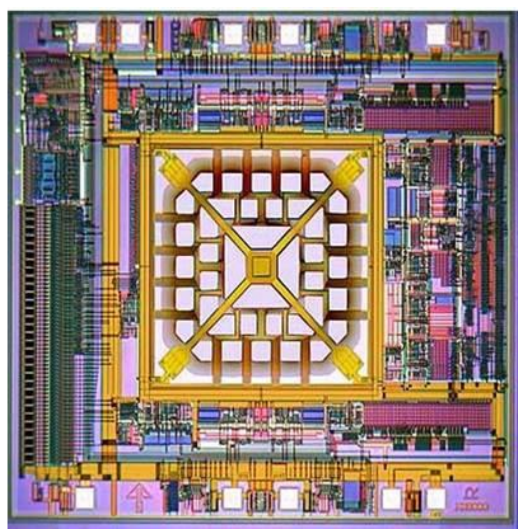
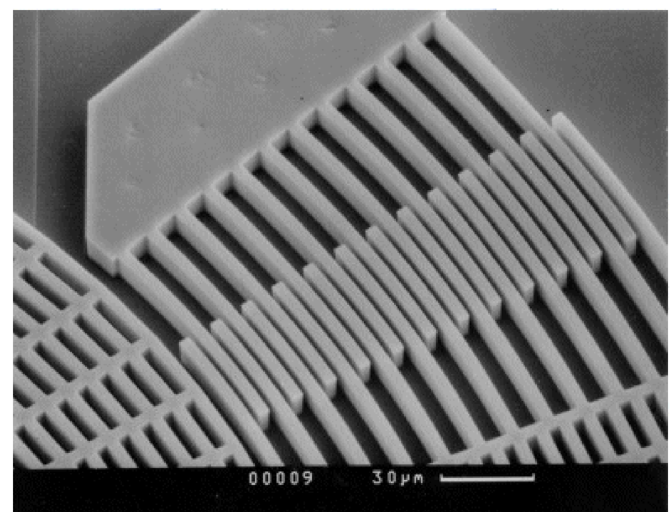
Gyro Types - Sensors

Low cost MEMS Gyros

High End Gyros
Ring laser, fiber optic, hemispherical resonator

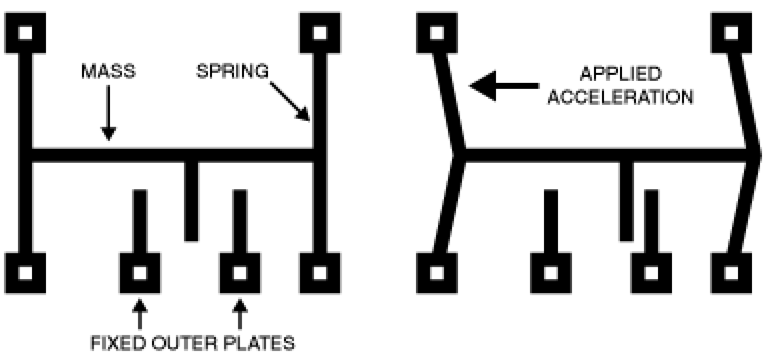
What is MEMS?

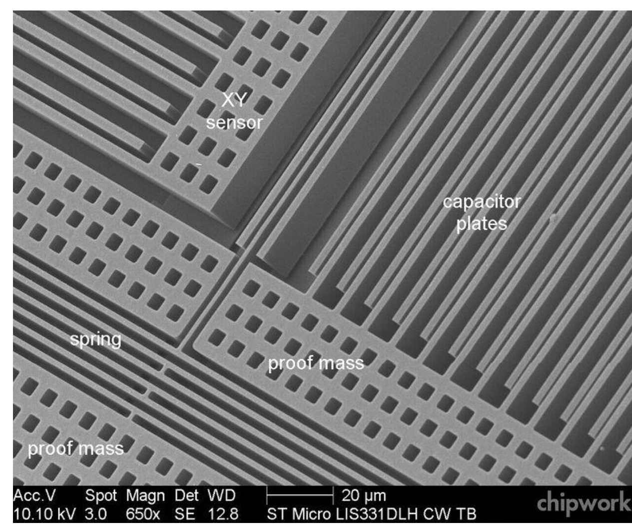
- MEMS stands for Micro-Electro-Mechanical Systems
- MEMS devices are miniscule electro-mechanical elements made using microfabrication techniques
- Accelerometers, gyros, microphones, optical switches and DLP chips are examples of MEMS devices

MEMS Accelerometers

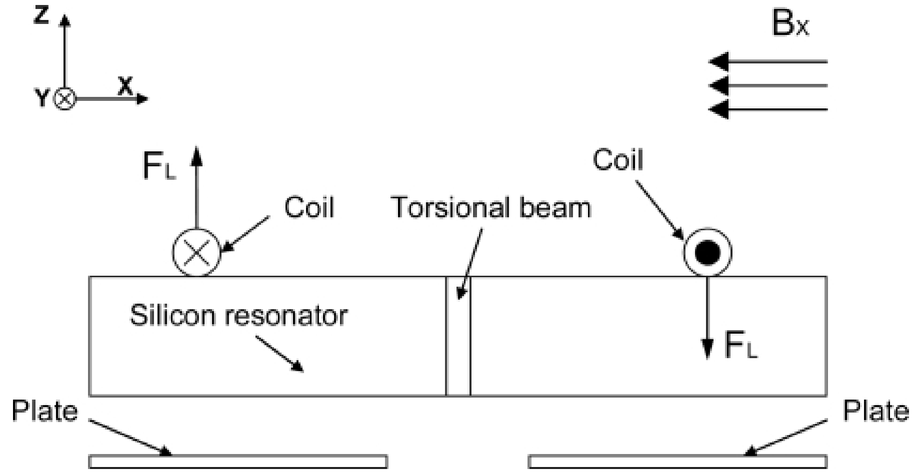
- Detects instantaneous acceleration through a given axis by detecting changes in the test mass's location
- 1, 2 and 3 axis versions available
- Interfaces include analog, TWI, serial, etc.
- Select for range, resolution and accuracy





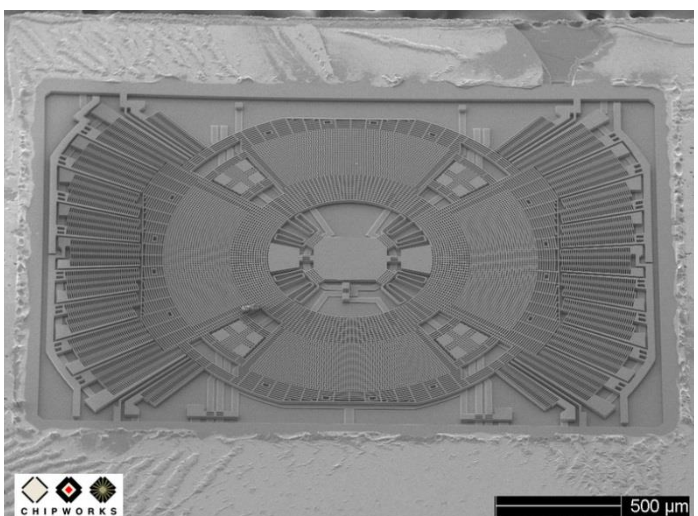
MEMS Magnetometers

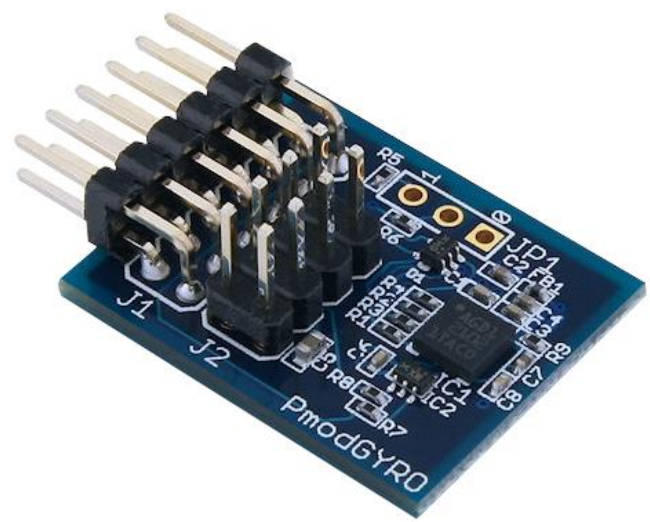
- Detects the instantaneous orientation of the object using it compared to the magnetic fields in the same space as the object. Most operate by detecting aspects of the Lorentz Force
- 1, 2 and 3 axis versions available
- Interfaces include analog, TWI, serial, etc.
- Select for resolution, accuracy and stability



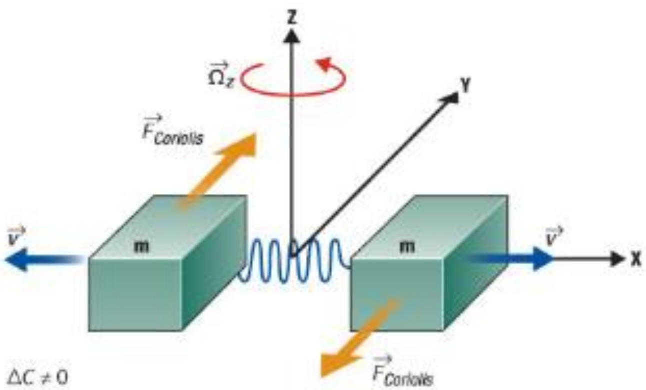
MEMS Gyros

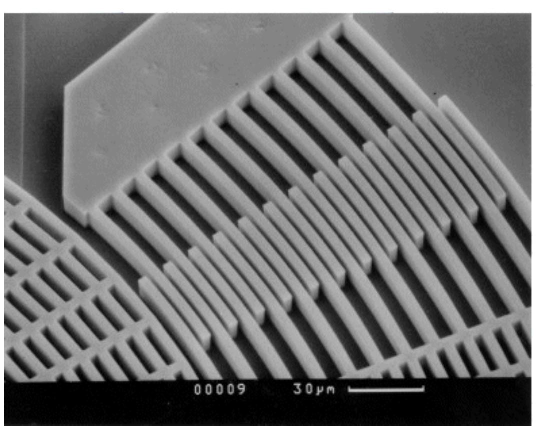
- Detects instantaneous speed of rotation through a given axis by detecting changes in the test mass's location
- 1, 2 and 3 axis versions available
- Interfaces include analog, TWI, serial, etc.
- Select for range, resolution, accuracy and stability





How does it work?

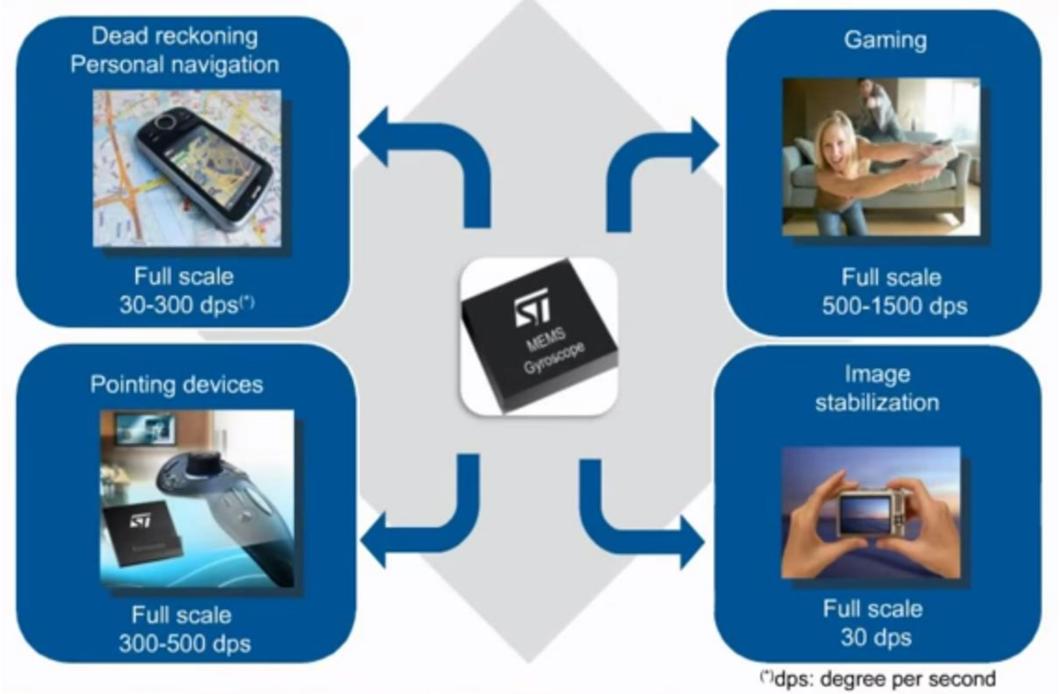




- Vibrating proof/test masses exhibit angular momentum
- Coriolis effect creates torque orthogonal to rotation according to the right hand rule.
- Test masses vibrate in opposite directions, mitigating the effects of linear accelerations
- Sensing is usually done with capacitative combs

Sensitivity

- Refers to the range of rotation the gyro can accurately represent in DPS
- Some gyros have user-selectable sensitivity

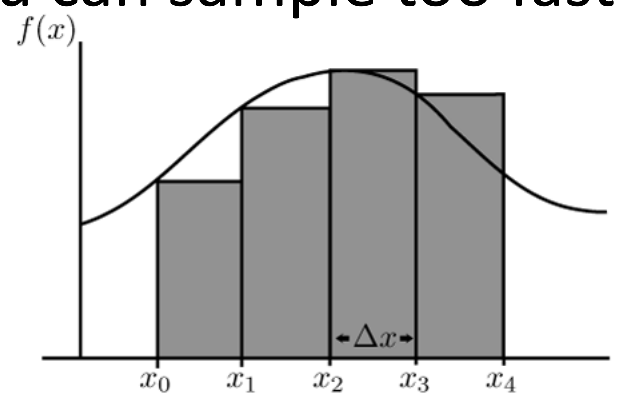


Calibration

- All gyros have drift, and MEMS gyros tend to get far more drift than others
- Drift varies with temperature
- Drift can be measured and compensated through calibration
- Some gyros have built-in auto-calibration
- Example: Measure 100 samples while robot is stationary, calculate mean drift bias to subtract from future readings

Integration

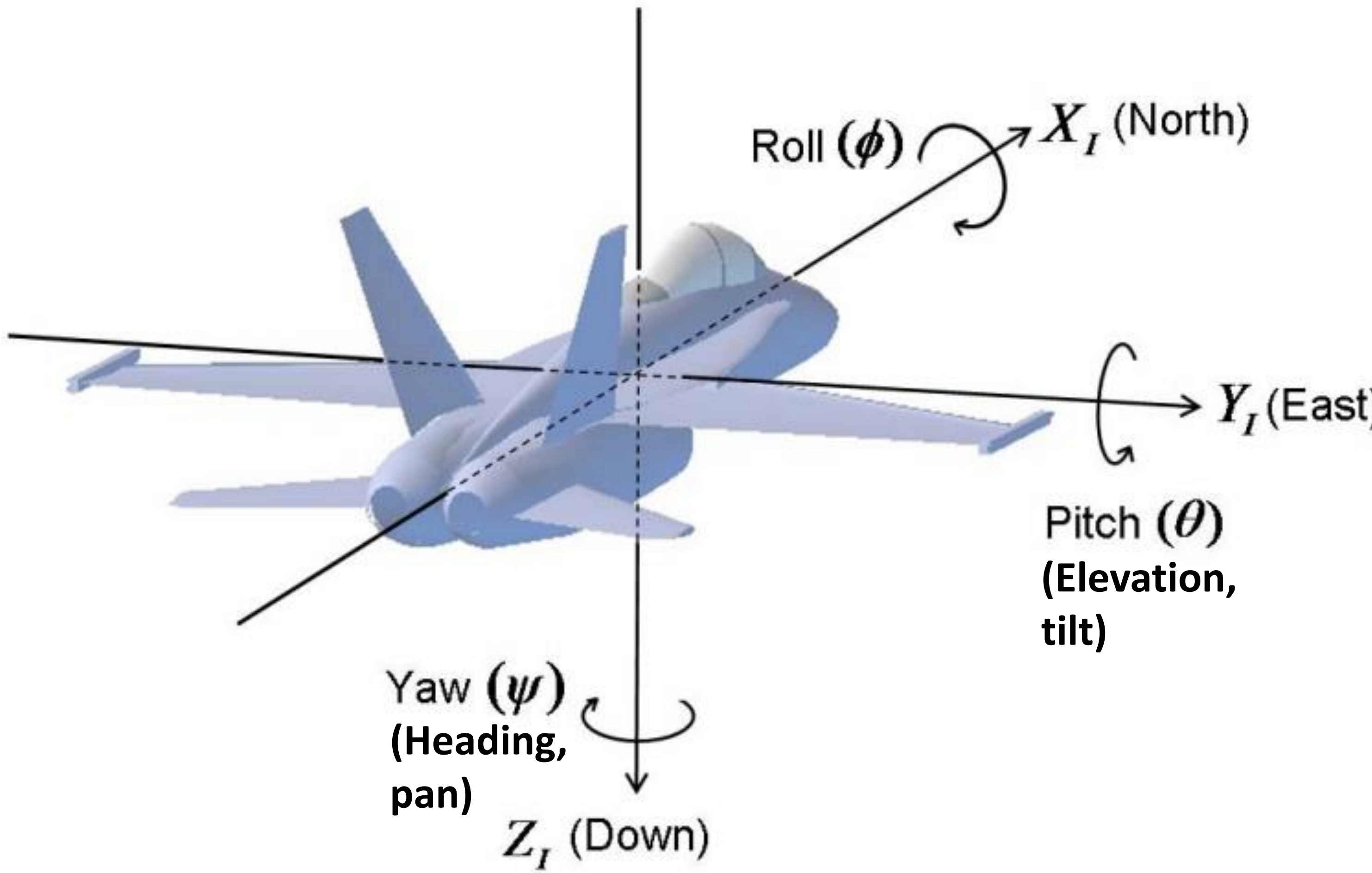
- Gyros only give instantaneous rate of rotation, so results must be integrated to find actual change in angle over time
- General equation: $\theta = \theta + (\text{reading} - \text{bias}) * \Delta t$
- Time elapsed between samples is best kept small to limit truncation errors
- Optimal sample frequency is most affected by the sensor's sensitivity and how fast the robot will likely rotate – yes you can sample too fast



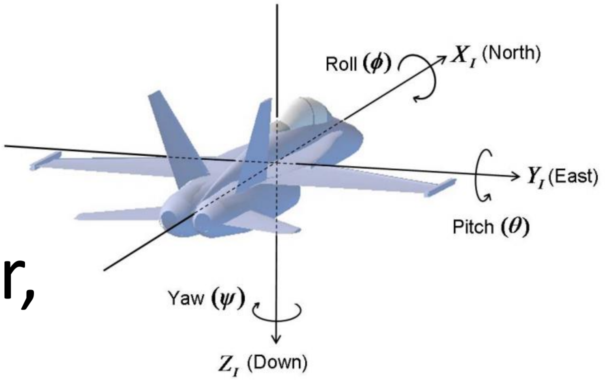
Drift Compensation

- Drift still remains after calibration, and is amplified during integration
- Recalibrating if possible helps to keep drift low; this is especially important if temperature changes (i.e. environmental change or internal heating)
- A simple strategy is to keep gyro use low/occasional and integrate only when necessary (make turns relative)
- The best strategy is to use a complimentary sensor to cross-check for drift
  - Balance: accelerometer
  - Heading: magnetometer-outdoor
- Using the environment to reorient the robot to a known heading, like backing into a wall, can reset growing error

Yaw, Pitch and Roll



Coordinate Systems



- Body frame of the robot (gyro, accelerometer)
- World Coordinates (magnetometer, accelerometer)
- Where am I pointing (orientation)
  - Euler angles, quaternions, compass heading
- Where am I (location)
  - Cartesian, polar, GCS (latitude, longitude, elevation)

Balance – Pitch and the missing accelerometer

- Gyroboy – instructions and program ship with Mindstorms. Has only a single axis gyro, no accelerometer.
- Balance bot MUST overcorrect – so they oscillate around the balance point
- EMA helps locate that center of balance even when it drifts slowly, so can be used to update the bias estimate
- Headwind Thought Experiment
  - Accelerometer could be a nuisance preventing leaning into the wind – robot topples backward
  - Remove headwind and EMA will take too long to unwind the compensating bias – robot topples forward
- Accelerometer likely more robust during abrupt disturbances

Gyro-Based Turns - Yaw

- Keep turns short and relative
- Turn until the integrated angle has been reached
- PID can be used to make these turns more accurate by removing inherent overshoot
- Demo – GyroTurn (IRBot, Argos?)

Maintaining a Heading – no Yaw

- May wander off target on long stretches
- Try to keep the gyro reading constant by turning opposite to changing heading
- PID is also useful here to lower error by making the process more like following an invisible line
- Demo – GoYonder (IRBot?)

IMU and AHRS

- Combine multi-axis gyros, accelerometers and magnetometers for 6-9 DOF solutions.
- IMU = Inertial Measurement Unit (Water and Land Vehicles)
- AHRS = Attitude and Heading Reference System (Aviation)
- Likely to have on-board microcontroller
- AHRS more likely to offer fused virtual orientation sensors

IMU/AHRS Sensor Fusion

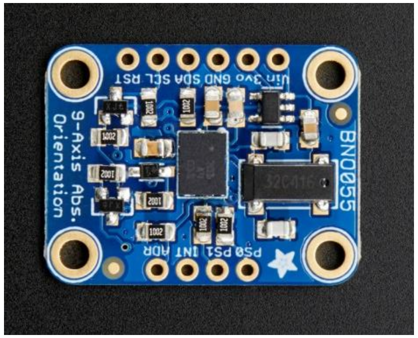
- Accelerometer corrects gyro drift orthogonal to gravity
- Magnetometer corrects yaw gyro drift relative to magnetic north
- Sensor fusion uses particle filters to cross-correct individual sensors while accounting for their different kinds of errors.

Where does it go (on the robot)?

- After alignment with important axes, does position on the robot matter?
- Gyros: Does not matter - caveats.
- Accelerometers: Near the center of rotation (mass)?
- Magnetometers: Away from other electronics and as high as possible

Low Cost IMUs

$75 9 DOF Razor IMU



Bosch IMU

[$125 UM7-LT Orientation Sensor]

Smartphone IMU - YMMV

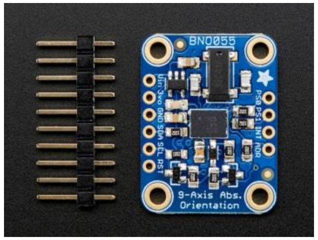
- Most have 3dof accelerometers and 3dof magnetometers
- iPhone 4 – 1^{st} mass market 3dof gyro
- Android higher end devices
- Quality varies
  - iPhone 6 bad batch
  - Moto G 2^{nd} gen sensor fusion erratic
  - ZTE Speed has no gyro, eliminating some virtual sensors
  - Sensitivity optimized for hand-held use

Android Orientation

- Direct Motion Sensors
  - TYPE_ACCELEROMETER
  - TYPE_GYROSCOPE_UNCALIBRATED
  - TYPE_MAGNETIC_FIELD
- Virtual Motion Sensors
  - TYPE_GRAVITY
  - TYPE_LINEAR_ACCELERATION
  - TYPE_GYROSCOPE
  - TYPE_ROTATION_VECTOR
  - TYPE_GAME_ROTATION_VECTOR

Your Gyro Options?

Hitechnic Gyro
via Legacy Module



Bosch IMU bno055
or other IMUs
via Device Interface Module

Moto G gen 2
Built-in sensors

Further Information

- Google TechTalks - Sensor Fusion: https://www.youtube.com/watch?v=C7JQ7Rpwn2k
- ST Micro's Gyro Video: https://www.youtube.com/watch?v=A03AENwOVNY&feature=youtu.be&t=4m39s
- Understanding Euler angles: http://www.chrobotics.com/docs/AN-1005-UnderstandingEulerAngles.pdf
- Understanding Quaternions: http://www.chrobotics.com/docs/AN-1006-UnderstandingQuaternions.pdf
- CH Robotics orientation sensor vids: https://youtu.be/Ho44RQ3TnlM?list=PL7YOL1oEKMMBjJ5jlVYgz84Dp_cAvuJnV
- Android motion sensors: http://developer.android.com/guide/topics/sensors/sensors_motion.html
- David Anderson's Tao of Robotics: https://www.youtube.com/watch?v=8CXReb7f0Eo