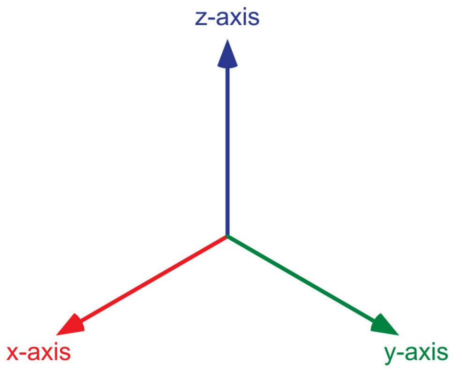
IMU : Inertial Measurement Unit

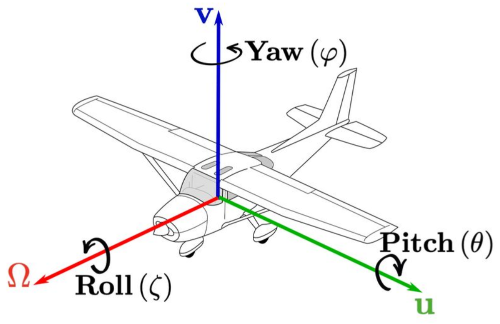
General operating principles

Components

- IMUs most often have 3 different components
    - Accelerometer : measures acceleration of the unit
    - Gyroscope : measures orientation and angular velocity
    - Magnetometer : measures magnetic fields
- These three different components are put onto a single SOC
    - In our case the BN055
- We will only be focusing on
    - Accelerometer
    - Gyroscope



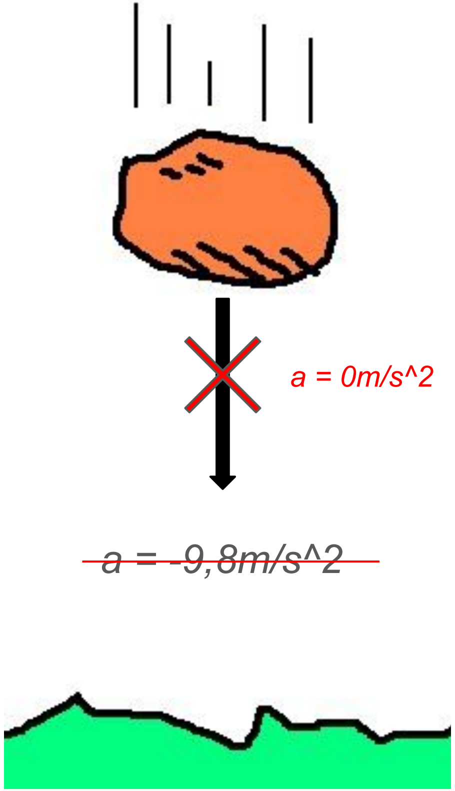
Accelerometer axes



Gyroscope axes

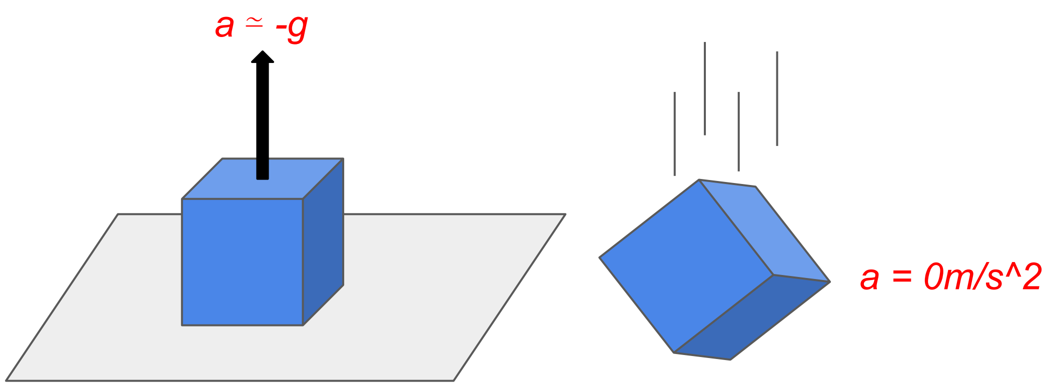
Accelerometer

- Measures the proper acceleration
  - *i.e.* The rate of change relative to an observer who is in freefall
  - The frame of reference is the observer who is in freefall
- Why measure it like this?
  - More accurate in the case of multipally accelerated systems
  - *e.g* Moving on a train, moving on a car, *etc.*



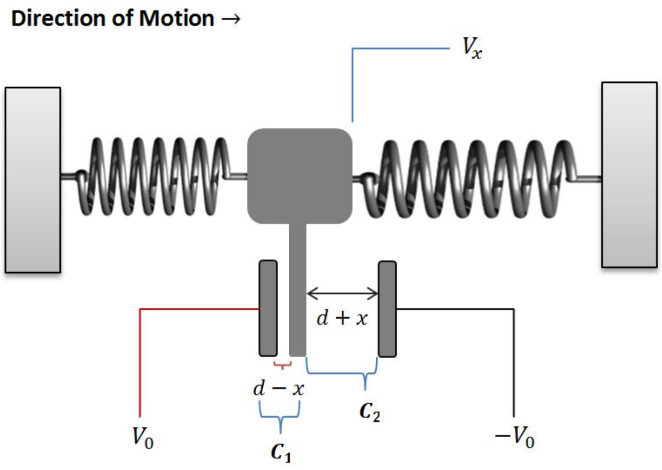
Accelerometer : Impacts of measuring proper acceleration

- On the ground at standstill, the accelerometer will always have a *positive upward acceleration*
    - Note : Will not be exactly *-g* as there is an offset caused by earth's rotation
    - Device needs to be calibrated to deduce these offsets



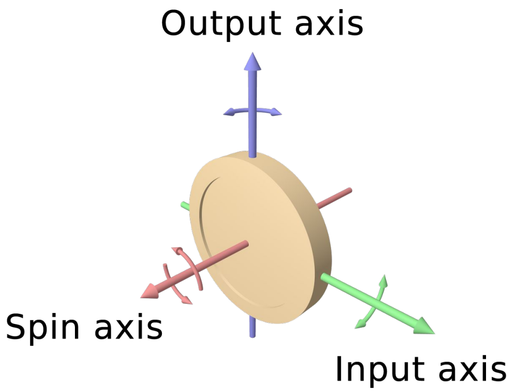
Accelerometer : Operating Principle

- 3 different accelerometers
  - One for each degree of motion (X,Y,Z)
  - Restrict measurement to one axis per accelerometer (stay in plane)
- Damped mass on a spring
  - MEMS : microelectronic mechanical systems
  - Tiny systems embedded in SOC
- Mass is connected to a resistance or capacitance that varies with movement
- Outputs analog or digital measurement



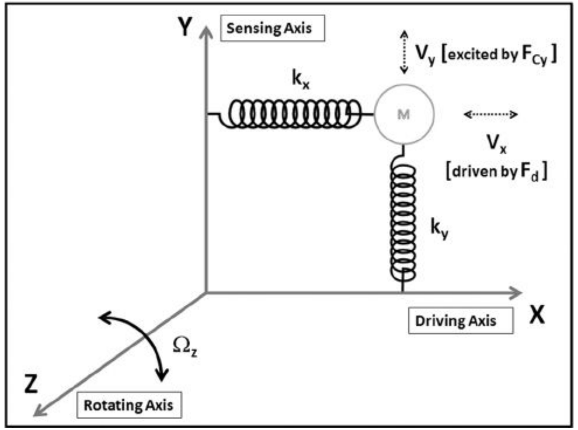
Gyroscope

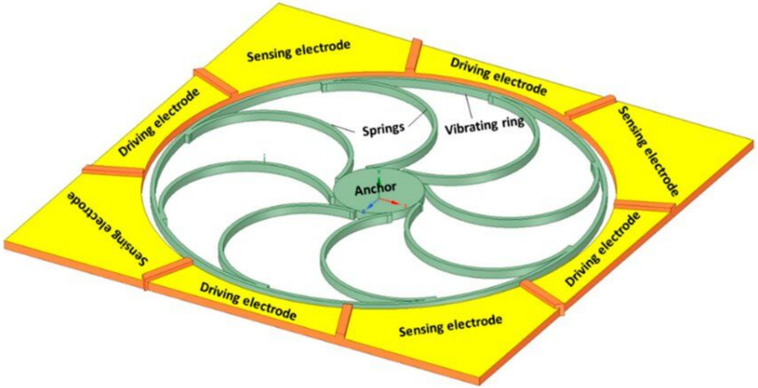
- Measures orientation and angular velocity
- Original operating principle : rotating disk
  - Wheel will resist changes of orientation by applying a force in the opposite direction
  - Similar to a bicycle wheel or an inductor/magnetic field
- Applying force to input (roll) will generate output force (yaw)



Gyroscope : Operating Principle

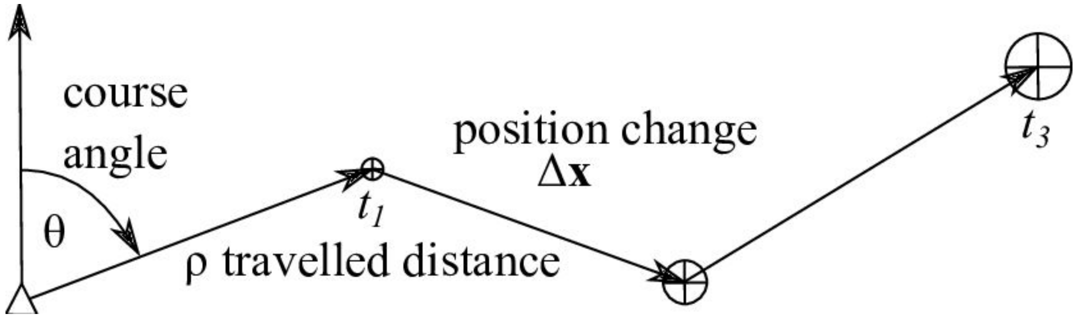
- Modern sensors do not use spinning wheels anymore
- Vibrating Structure Gyroscopes
    - Use the *coriolis effect*
    - *i.e.* deflection of trajectory of objects moving with respect to a rotating plane
    - *e.g.* winds getting deflected, rotation of cyclones
- How is this effect used?
    - Quite complicated, details not important
    - Vibration continues in same plane even if support rotates
    - Coriolis force causes the vibrating object so exert a force which can be measured
    - Implementation is more complex





Using an IMU

- IMUs can be used in a wide variety of applications
    - *e.g.* motion sensing, fitness trackers, airbags, power tools, aircraft, *etc.*
- We are using it in the context of an *Inertial Navigation System* (INS)
- These systems imply using *dead reckoning* calculations to estimate the position
    - *I.e.* using the computation of displacement from the previous known position to estimate the current position



The problem of *drift*

- Drift accumulates over <u>time</u> <u>and not distance or velocity</u>
    - There is always an output from the sensor, regardless of the distance travelled or the velocity at which the sensor is travelling
    - Computing continuously from this value will give the drift
- How big is this drift?
    - Military grade IMUs accumulate 50 meter offset drift in 15 minutes of use
    - Drift accumulation is important and an issue
- How to minimize?
    - Zero Velocity Update : stopping and standstill for a certain time will enable a reference and prolong accuracy of the system
- INS need to be used in combination with another system for accurate and usable data
    - Another system : *e.g.* GPS, LiDar, reference points,*etc.*

Sensor Fusion Software

- “Secret Sauce” that give you values that mean something
- Kalman filtering to combine sensor data
- Result is stable value
- Proprietary software that comes with BNO055 sensor
- This is why computing *yaw* from raw data is very unstable

Tilt compensated heading estimation (eCompass)

This algorithm leverages data from an accelerometer and a magnetometer to compensate for the tilt of a device, enablir it to provide accurate readings of magnetic fields. The algorithm is used in applications such as electronic compasse and navigation systems where accurate representation of magnetic fields is crucial.

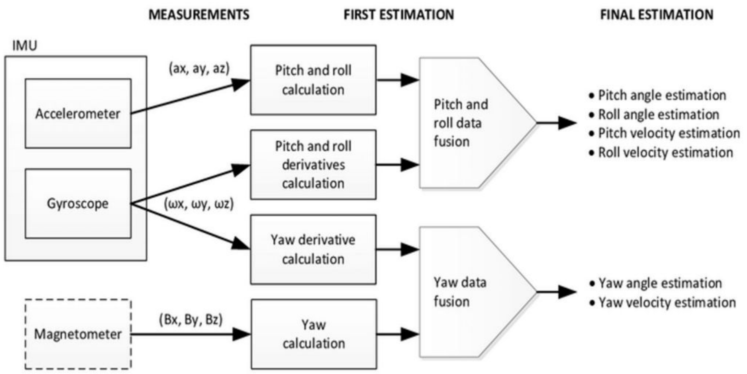


Figure 2: Functional block diagram of BSX orientation estimation

Conclusion

Points to remember

- Frame of reference of the accelerometer values is in *freefall*
- At rest, there should be a positive upward acceleration about equal to *g* = *9,8*
- Drift accumulates with <u>time</u>
- Sensor fusion software is the secret ingredient