Sensors:

Needs:

- Data redundancy
- Data for both situations: eclipse and sun
- Question of sampling frequency
- Location and size/weight
- Ability to resist to environment
- Low consumption
- Low price

a) Gyroscope

Micro Electro-Mechanical (MEM) Gyroscopes:

MEMs gyroscopes have some form of oscillating component from where the acceleration and hence direction change, can be detected. This is because the conservation of motion law says that a vibrating object continues vibrating in the same plane, and any vibrational deviation can be used to derive a change in direction.

Advantage:

- Compact
- Affordable

Disadvantage:

- Noisy: drift ~0.5° per minute

Figure 1 : Micro Electro-Mechanical (MEM) Gyroscopes

Stellar:

This device tracks the motion of stars in the field of view. Stars are detected using the difference of color between pixels. Attitude propagation is based on successfully performing correspondence of these stars between camera frames.

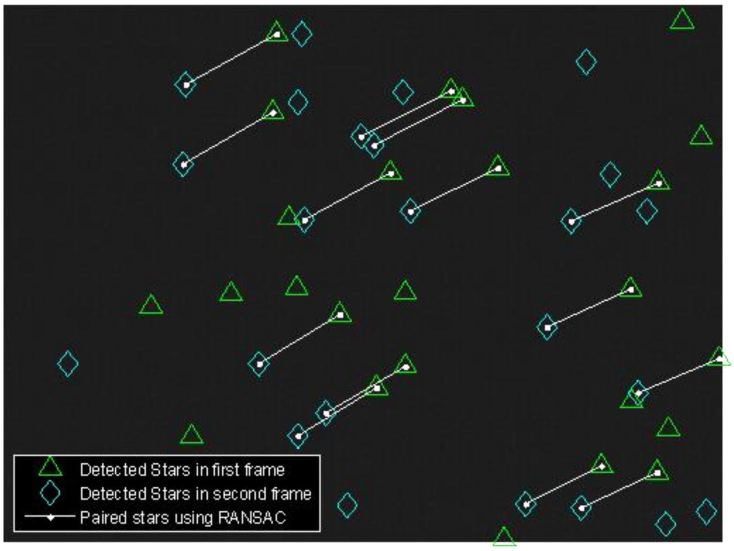

Figure 2 : Stellar

Advantage:

- Tolerates large amount of noise
- Can assist MEMS gyros by limiting drift

Disadvantage:

- Requires a digital signal processor on board the spacecraft
- Add computational requirement
- Too large for a CubeSat

Ring Laser gyroscope (RLG):

A **ring laser gyroscope** consists of a ring laser having two independent counter-propagating resonant modes over the same path; the difference in the frequencies is used to detect rotation.

Advantage:

- High accuracy

Disadvantage:

- Large
- Expensive

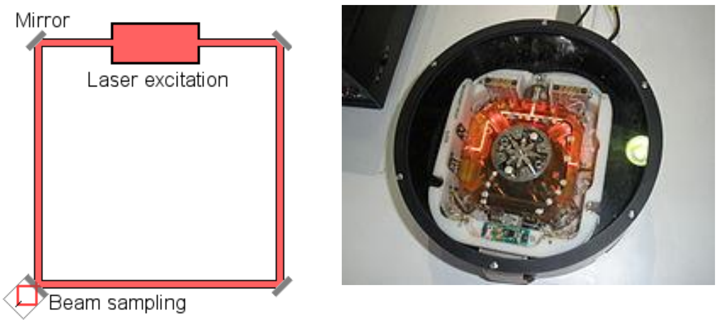

Figure 3 : Ring Laser gyroscope (RLG)

Piezo Gyroscope:

Use the deformation of a piezo electric bar to calculate the angle.

Advantage:

- High accuracy
- Quick
- Lightweight

Disadvantage:

- Vibration
- Need high speed processor

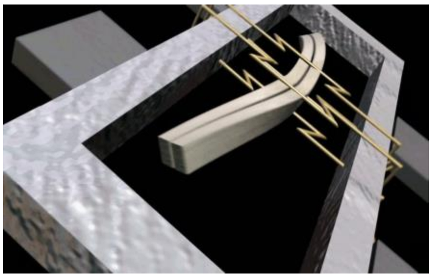

Figure 4 : Piezo Gyroscope

b) Gyrometer

Gyrometer is an instrument which measures an angular acceleration. Two types exist:

Optic

A fiber optic gyroscope (FOG) senses changes in orientation using the Sagnac effect, thus performing the function of a mechanical gyroscope. However, its principle of operation is instead based on the interference of light which has passed through a coil of optical fiber which can be as long as 5 km.

Figure 5 : Optic Gyrometer

Advantages:

- extremely precise
- No moving parts => most reliable to the mechanical gyroscope

Disadvantages:

- Requires calibration
- Too big for a CubeSat

Mechanic

Thanks to rotation parts, it can use the inertial moment not to move the central access and calculate its inclination to the support.

Advantage:

- No calibration needed

Disadvantages:

- Doesn't work in space
- too big for a CubeSat (takes a lot of space)

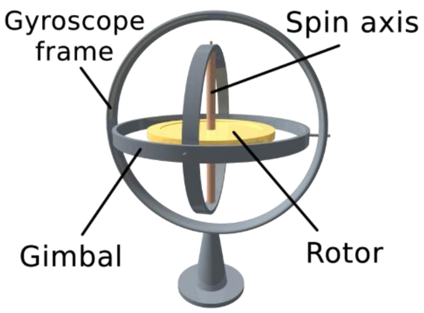

Figure 6 : Mechanic Gyrometer

c) Sun sensor

It is an optical device that detect the position of the sun. The photons coming from the sun enter in a photosensitive chamber. Using two sensors perpendicular to each other, the direction of the sun can then be determined.

The output can be either discrete or analog.

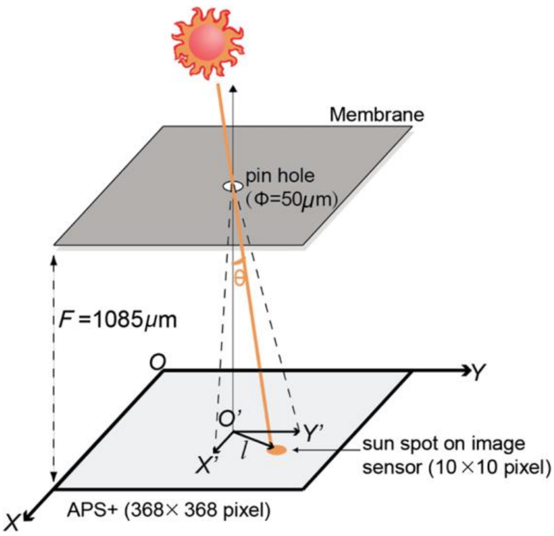

Figure 7 : Sun Sensor operation

Sun Sensor IDD-Ax (analog)

Advantages:

- High reliability
- Low power consumption

Disadvantages:

- Accuracy (1° in Field of View of 30°)

Coarse Bi-axis sun sensors

Advantages:

- Low cost
- High strength
- High temperature range
- Standard FOV

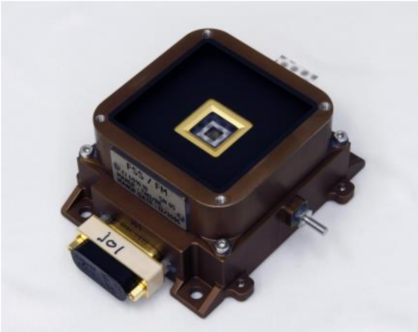

Figure 8 : Bi-axis sun sensors

Disadvantages:

- They need direct sunlight (so they need to be on the sides of the CubeSat)

d) Star tracker

This optical device images a part of the sky and compares it to a map from the memory. This helps it to determine its orientation relatively to the stars

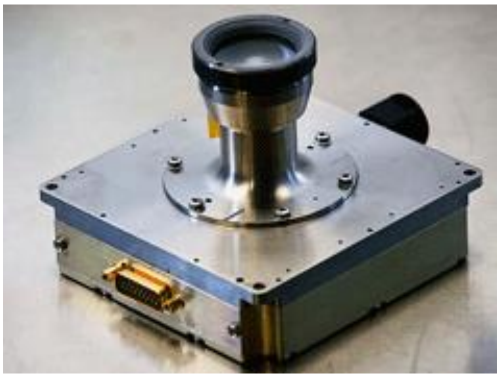

Figure 9 : Star Tracker

Advantages:

- High accuracy

Disadvantages:

- Need a reference map
- Need heavy data processing
- Size and weight (too much for a CubeSat)

e) Horizon sensors

Figure 10 : Horizon sensors

Uses the relative difference between the dark of space and the light of earth to find earth's horizon.

Advantages:

- Low cost
- Fast response time

Disadvantages:

- Low accuracy (about 1°)

f) Magnetometer

A Magnetometer is a device that measures a magnetic field. There is a lot of different methods to do so but some are better for CubeSat.

Laboratory magnetometers

- Superconducting quantum interference device:
    - Extremely sensitive but noise sensitive
- Inductive pickup coils:
    - Detects the current induced in a coil
- Vibrating sample magnetometer (VSM):
    - Uses vibration of sample inside a coil in order to detect induced current
    - Heat due to vibration can be a constraint
    - Fragile sample can be impractical
- Pulsed Field extraction magnetometer:
    - Similar to VSM but this time it is the magnetic field that changes instead of the sample's vibration.
- Torque magnetometer:
    - Indirect measure of magnetism: measures the torque resulting from a uniform magnetic field

- Faraday force magnetometer:

    - Uses gradient coils
- Optical magnetometer:
    - Uses light on a sample which leads to an elliptical measurable trajectory

Disadvantages:

-Needs samples

Survey magnetometers

- *Scalar magnetometers* (measures the strength of the magnetic field but not the direction:
    - Proton precession magnetometer (uses nuclear magnetic resonance to measure the resonance frequency of protons)
    - Overhauser effect magnetometer
    - Caesium vapour magnetometer
    - Potassium vapour magnetometer

- *Vector magnetometers* (measures the component of the magnetic field in a particular direction):
    - Rotting coil magnetometer:
        - Uses a rotating coil to induce a sin wave
        - Old technology
    - Hall effect magnetometer:
        - Produces a voltage proportional to the applied magnetic field
        - Used where the magnetic field strength is relatively large
    - Magneto resistive devices
    - Squid magnetometer
    - Spin exchange relaxation free atomic
    - magnetometers
    - Fluxgate magnetometer

Fluxgate magnetometer

The principle of this magnetometer is to use 2 coils: one is alimented with an alternative current, in the other coil the induced AC is measured (intensity and phase). When a change occurs in the external magnetic field, the output of the secondary coil is changed. This change can then be analyzed to determine the intensity and orientation of the flux lines.

Advantages:

- Electronic simplicity
- Low weight

Disadvantage:

- Can be sensitive to magnetic perturbations coming from inside the spacecraft

RECAP magnetometers:

Spacecraft magnetometers basically fall into three categories: **fluxgate, search-coil and ionized gas magnetometers**

With the data collected from the magnetometer, we can with the **B-Dot** controller (or also the B bang bang) in link with the International Geomagnetic Reference Field (**IGRF**) determine the **magnetic field vector**.

g) Temperature sensors

A lot of measuring technologies exists:

- Thermometer:

  It is a device that measures temperature or a temperature gradient

- Bimetal:

  A Bimetal is an object that is composed of two parts of metal, joined together. When the temperature changes one of those two parts changes size which results in a deformation. The device measures this deformation.

- Thermocouple:

  A thermocouple is an electrical device consisting of two different conductors forming electrical junctions at different temperatures. It produces a temperature dependent voltage as a result of the thermoelectric effect, and this voltage can be interpreted to measure the temperature.

- Resistance thermometers:

  Same as thermocouple, but the resistance changes value when the temperature evolves (it replaces thermocouples in industrial applications below 600°C)

- Silicon bandgap temperature sensor

  This extremely common sensor is used in electronic equipment. The main advantage is that it can be included in a silicon integrated circuit at very low cost. Here is the output voltage from the sensor:

$$V_{BE} = V_{G0}(1 - \frac{T}{T_0}) + V_{BE0}(\frac{T}{T_0}) + (\frac{nKT}{q})ln(\frac{T_0}{T}) + (\frac{KT}{q})ln(\frac{I_C}{I_{C0}})$$

  Where:

  T = temperature in Kelvin
  T_0 = *reference temperature*
  V_{G0} = bandgap voltage at absolute zero
  V_{BE0} = junction voltage at temperature T_0 and current I_{C0}
  K = Boltzmann's constant
  q = charge on an electron
  n = a device-dependent constant

h) Summary

There is a lot of sensors, some of them need the sunlight, but as we will rotate around the Earth, we will also have to manage the CubeSat's attitude during the eclipse phase. Moreover, redundancy is a necessity for sensors.

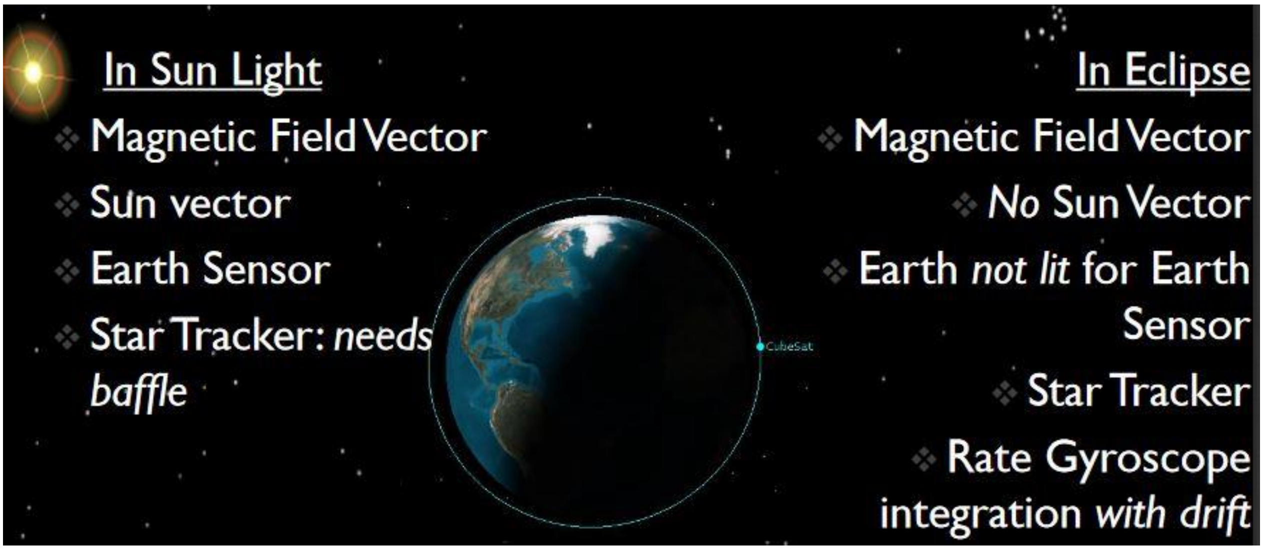

Figure 11 : Activity sensors in sun light and in eclipse

The following figure presents the sensors which can be used in each case:

Looking at this data some tendency can identified:

- We need two vectors during both the eclipse and sun lit phase. that is why the sensors we think to use would be:
  - Sun sensor (to get sun vector but does not work while in eclipse)
  - Magnetometer to get the magnetic field vector (also works while in eclipse)
  - Another sensor for the eclipse phase (probably MEMS gyroscope)