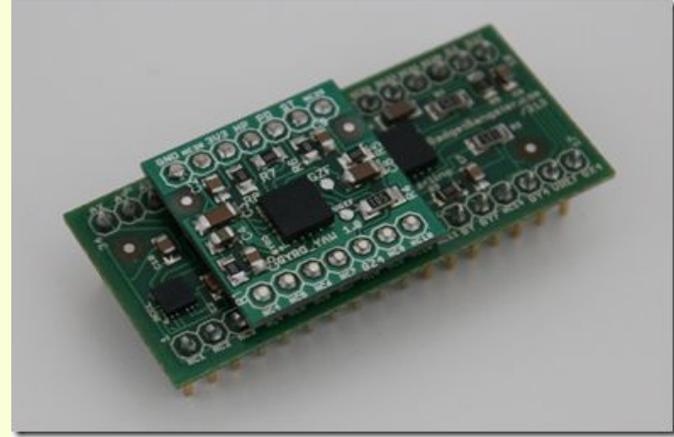


Introduction to IMU

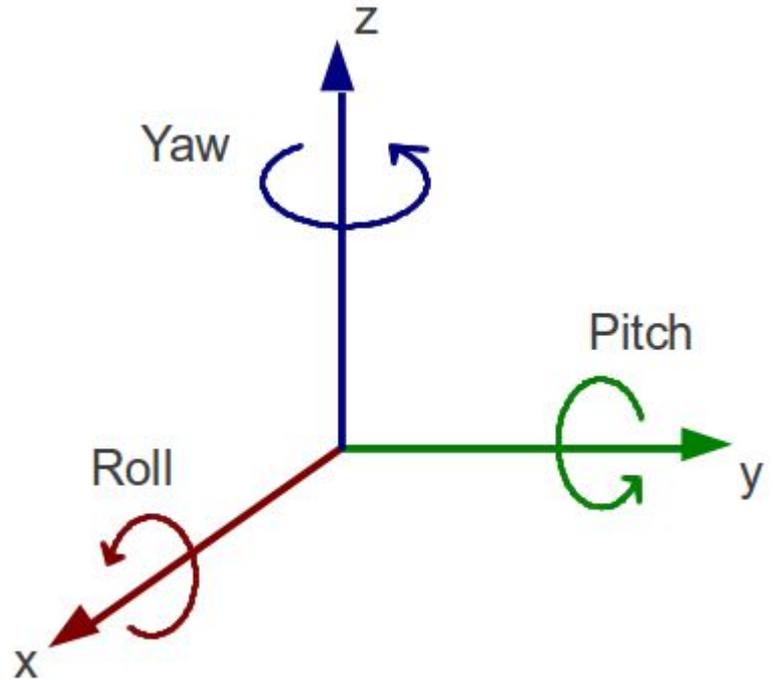


What is an IMU(Inertial Measurement Unit)?

- An *inertial measurement unit* (IMU) is an electronic device that measures and reports a body's specific force, angular rate, and sometimes the magnetic field surrounding the body, using a combination of accelerometers and gyroscopes, sometimes also magnetometers.
- A 3-axis accelerometer measures acceleration along the X,Y,Z axes of the IMU.
- A 3-axis gyroscope measures angular velocity about the X,Y,Z axes of the IMU.
- A 3-axis magnetometer measures the magnetic field intensity along the X,Y,Z axes of the IMU.

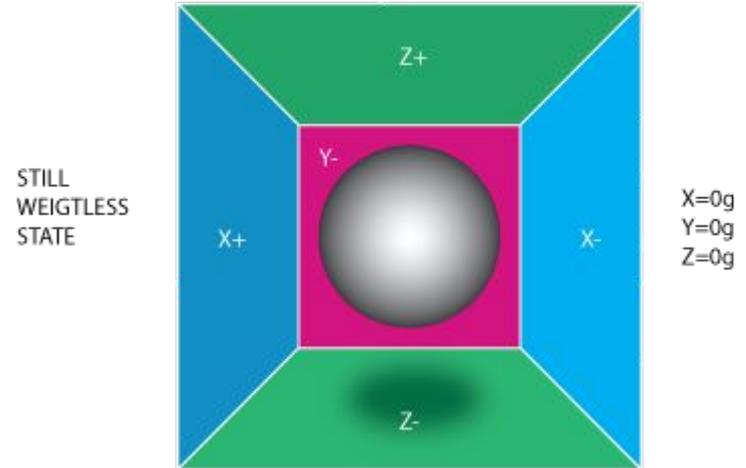
Fundamentals

- The following angles are defined as the roll(X-axis), pitch(Y-axis) and yaw(Z-axis).
- Our main reason for using an IMU is the ease with which we can calculate these angles.

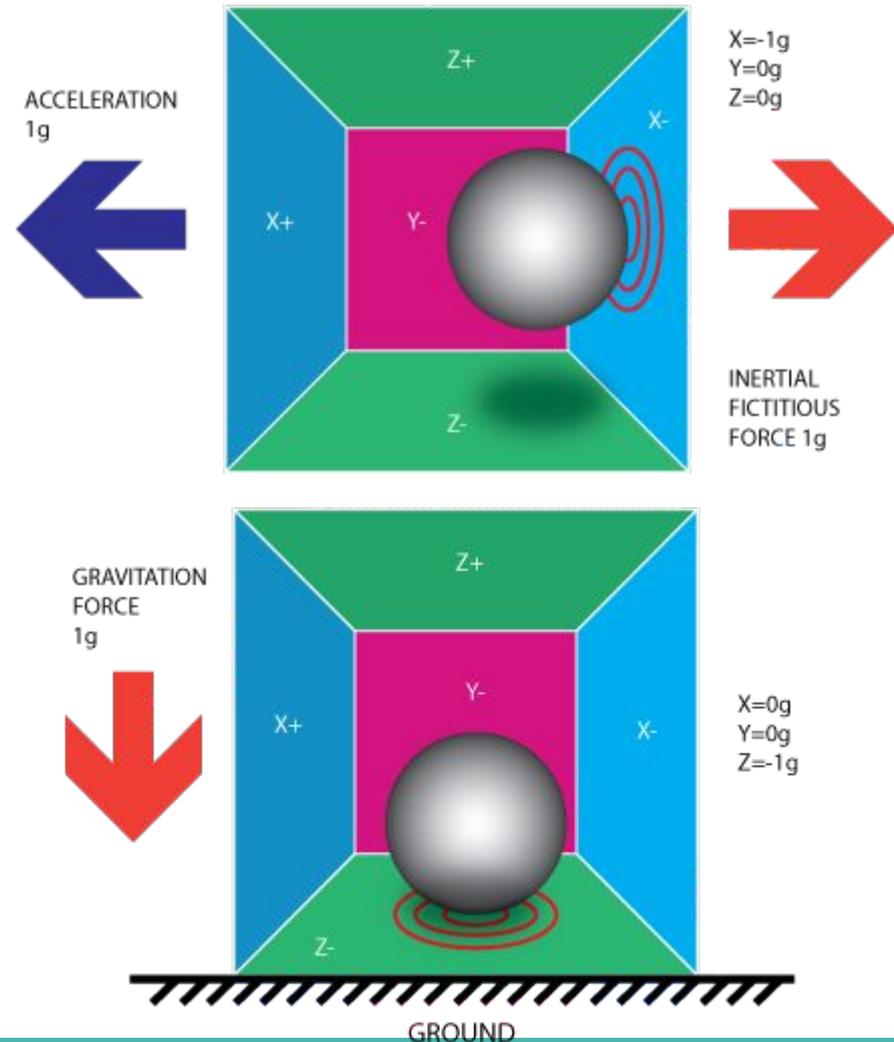


Accelerometer

- Accelerometer: An **accelerometer** is a device that measures proper acceleration; proper acceleration is not the same as coordinate acceleration (rate of change of velocity). For example, an accelerometer at rest on the surface of the Earth will measure an acceleration due to Earth's gravity, straight upwards (by definition) of $g \approx 9.81 \text{ m/s}^2$
- The working of an accelerometer can be easily understood by a ball in a box model. Currently the box is in a weightless state (free-fall).



- Consider the box accelerating in the +X direction with an acceleration $1g$. Due to this the ball applies a normal force of $1g$ on the opposite side of the wall
- Here, acceleration measured along X-axis is $-1g$.
- Now in the second case the IMU is kept still on the ground. Due to gravitational force, the IMU measures acceleration along Z-axis as $-1g$.

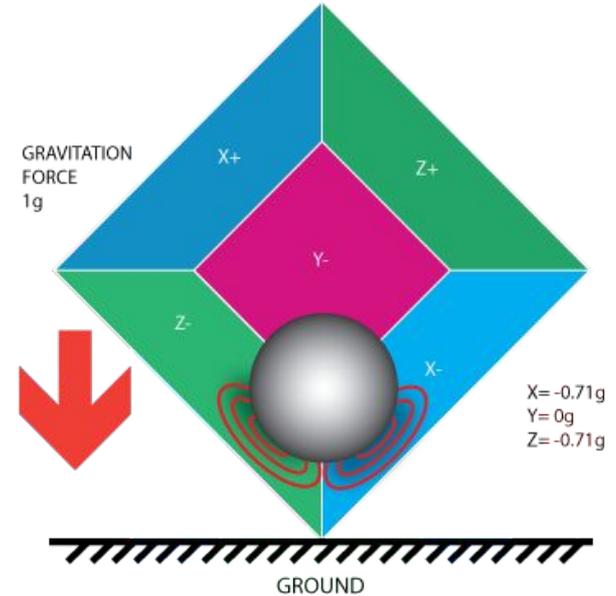


The previous cases dealt with accelerations along single axes.

Now, suppose the box is rotated clockwise by an angle of 45 deg to the right . Now acceleration measured on the the IMU is

$$X=-0.71g , Y=0g, Z= -0.71g$$

Here, $0.71 \times 0.71 = 0.5$. Thus the accelerations measured on these two axes is the component of gravitational acceleration. From this we can determine the orientation of the box.



Calculating pitch, roll and yaw from Accelerometer

- Supposing we have the values of acceleration along the 3 axes, you can calculate the roll and pitch by the following method-

```
roll = atan2(Rx,Rz) * RAD_TO_DEG
```

```
pitch = atan2(Ry,Rz) * RAD_TO_DEG
```

- We cannot calculate the value of yaw using the accelerometer only. For calculating it we need data from gyroscope and magnetomer.

Gyroscope

- It provides the values of angular velocities along the 3-axes.
- We can obtain the change in pitch, roll and yaw by integrating these values, but to calculate absolute values of these angles we need reference data, which can be obtained from accelerometer or magnetometer.
- For calculating yaw, the data from IMU uses magnetometer data as reference and then integrates the gyro data.

Magnetometer

- A **magnetometer** is an instrument that measures magnetism—either **magnetization** of magnetic material like a **ferromagnet**, or the strength and, in some cases, direction of the **magnetic field** at a point in space
- Magnetometer gives the value of magnetic field intensity along the 3-axes of the magnetometer.
- Since the direction of earth's magnetic field is close to constant, we can use the magnetometer data to calculate the roll, pitch, yaw angles absolutely.

Calibrating Sensor Data

- Analog data in terms of an integer in the range 0-1023 can be obtained directly from the Analog X,Y,Z pins of the IMU.
- Digital ones might communicate using UART, SPI, I2C, or similar protocols
- Suppose the data obtained is A_nX , A_nY , A_nZ , G_nX , G_nY , G_nZ , M_nX , M_nY , M_nZ .

$$A_x = ((A_nX - A_{x0}) / 1023) * A_xS$$

Where A_{x0} = offset along X-axis, A_xS = Sensitivity of the Accel/Gyro/Magneto along X-axis.

Calibrating Accelerometer

A simple method for calibrating Accelerometer is -

1. Try to find configuration in which when the IMU is moved along Z-axis the only A_nZ changes.
2. Next, keep the IMU at rest in this configuration, the values of A_nX and A_nY in this state are A_{x0} and A_{y0} .
3. Now try to flip the IMU such that only the A_nZ data changes and the rest remain same.
4. The average of the A_nZ values in the 2 states is the A_{z0} value and their difference corresponds to a change of 2G. This gives sensitivity A_{zS} .
5. A_{xS} , A_{yS} can be calculated similarly by placing the IMU such that 1g acts along X and Y axes.

Calibrating Gyro and Magnetometer

For finding the gyro offsets, it is recommended to take the average of the gyro data when the IMU is at rest.

Calculating sensitivity for a gyroscope is much harder and is much inaccurate without the use of high accuracy machines like centrifuges.

It can still be performed by slowly rotating the IMU in one direction by a fixed angle and in the process integrating the Gyro data about that axis. The average gyro reading over that time is Angle/Time .

Performing this exercise and averaging the sensitivity data provides a better estimate.

Magnetometer offset and sensitivity can be calculated by a method similar to one used for accelerometers.

These values for offsets and sensitivities can be obtained from the datasheets of the IMU.

Tools for Calibration

Calibration described by the previous methods is too crude and inaccurate, so we use certain softwares designed primarily for calibrating IMU data. Though the principle of working for these might be difficult but they are easy to use. Some of them are

1. Magneto
2. FreeIMU Calibration Library

Magnetometer/Accelerometer data in different orientations of the IMU can be fitted on an ellipsoid. Using this property, these tools analyse the ellipsoid obtained and from this ellipsoid predict the offset and sensitivities values for these sensors.

Fusing Accel, Gyro and Magnetometer data

- The data from Accelerometer is very prone to noise from slight vibrations
- It can be improved by using data from the gyro which is much more accurate.
- If the roll obtained from Accel and Gyro and Magnetometer are R_a , R_g , R_m respectively, then the actual roll can be best estimated by-

$$R = (w_1 * R_a + w_2 * R_g + w_3 * R_m) / (w_1 + w_2 + w_3)$$

Where w_1 , w_2 , w_3 are the weights to given sensors depending on which is most accurate. Giving large values to w_2 gives cleaner output.

Suggested References

- http://www.starlino.com/imu_guide.html
- DCM-http://www.starlino.com/dcm_tutorial.html
- Kalman Filters-http://www.starlino.com/imu_kalman_arduino.html
- Quaternion-<https://en.wikipedia.org/wiki/Quaternion>
- FreeIMU Calibration Library
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