Implementation of Nonlinear Complementary Filter on $\mathbf{SO}(3)$ using IMU and Magnetometer

SC651 Hardware Project

Autumn 2025

1 Prerequisites

We will be using the same hardware setup and Arduino IDE for coding. You are requested to implement the following necessary steps before the actual nonlinear complementary filter implementation:

1.1 Sensor Interfacing

1. Obtain all three sensor readings: gyroscope, accelerometer, and magnetometer using the built-in functions (refer to LSM9DS1 library example codes if required). Ensure that the units are appropriate (Hint: Gyro units, Accelero units).

2. Choose an inertial frame (standard choice can be ENU frame). Ensure that all the sensor readings are in same body-frame by remapping (By default, they are not!). All the initial calibrations are supposed to be done with your body-frame aligned to the chosen inertial frame.

3. Do simple static bias calibration for the accelerometer and gyroscope. Do soft and hard iron calibration for the magnetometer. (**magneto** software will be given, you can use alternate software or MATLAB).

A class demo will be given for the sensor interfacing related requirements.

1.2 Matrix Operations

Install the eigen library (by Bolder flight Systems) in Arduino IDE for matrix operations. It has matrix and vector data types, basic algebraic operations and functions like **.transpose()** and **.cross()** (for transpose and cross product).

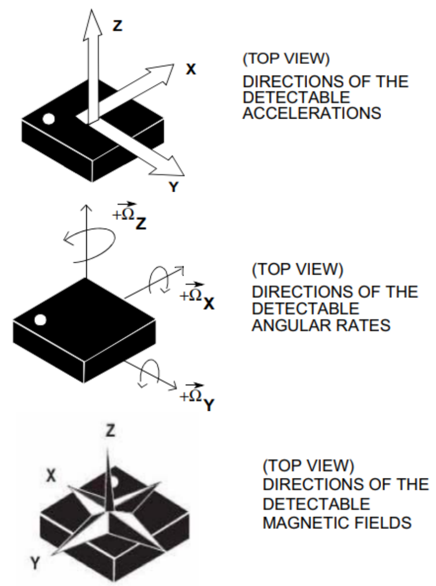

Figure 1: Actual sensor frames (refer datasheet)

2 Gyro Integration on $\mathbf{SO}(3)$

Implement simple gyro integration on $\mathbf{SO}(3)$ using gyro measurments. The discrete time equivalent for integration on $\mathbf{SO}(3)$ is

$$\dot{R} = R\Omega^{\times} \equiv R_{k+1} = R_k \exp(\Omega_k^{\times}\Delta t),$$
$$\dot{R} = \Omega^{\times} R \equiv R_{k+1} = \exp(\Omega_k^{\times}\Delta t)R_k.$$

For implementation, $\exp()$ can be approximated using the Rodrigues' formula

$$\exp(\Omega^{\times}) = I_3 + \sin(\theta)K + (1-\cos(\theta))K^2, \quad \theta := ||\Omega||_2,\ K = \left(\frac{\Omega}{||\Omega||_2}\right)^{\times}$$

3 TRIAD

Implement TRIAD using magnetometer and accelerometer (accelerometer as first vector). This can be used later as the direct rotation matrix measurement in the direct or passive complementary filter.

4 Nonlinear Complementary Filter on $\mathbf{SO}(3)$

Refer the original journal paper.

1. Implement direct, passive and explicit complementary filters on $\mathbf{SO}(3)$ with bias (for direct/passive, use TRIAD output as rotation matrix measurement). Tune the gains properly.

2. You are expected to have five different rotation matrix estimates at the end: Gyro integration, TRIAD and three different complementary filter outputs. Convert them to quaternions (use Eigen/geometry library function) and print as comma separated numbers for visualization. (you will be given python code for visualization).

3. Observe the differences in results in all five cases. Give your conclusions.