Optimal orientation tracking for inertial navigation systems

Supervisor: Colm Connaughton (Complexity and Mathematics)

Co-supervisor(s): Neil Cade

External stakeholder(s): Selex ES

Scientific background

In traditional target tracking problems it is usual to be primarily interested in the best estimate of where the target is, at the latest time, given all the previous data that we have collected. When that is the case the most obvious approach to take is that of iterative filtering; usually a Kalman filter where the fitting of a smooth curve to the finite data set is controlled by imposing a physically realistic model of the target dynamics (a stochastic difference or differential equation). This project is on the topic of inertial navigation of an airborne vehicle where we wish to find the best overall motion that is consistent with the inertial sensors carried on the vehicle. For the purposes of an MSc project, we confine attention to the rotational degrees of freedom. These are measured by three rate gyroscopes and three magnetometers. Magnetometers measure the component of the Earth's magnetic field along their axes. Rate gyroscopes measure the rate of change of their axis of orientation with respect to time.

Research challenge

The objective of the project is to use the noisy outputs of the magnetometers and rate gyroscopes to estimate the orientation of the vehicle. Rather than try to impose any approximation to the likely complex dynamics, this project is intended to address the regularisation by relatively soft constraints on the motion, letting the fitted trajectories be driven strongly by the data.

Given that we don't want to be deflected by any ideas of aerodynamic shape, we represent the vehicle as a 'brick'; sufficient to define an axis system and the sensor orientations. We can define the body-frame by unit vectors $\hat{\mathbf{x}}$, $\hat{\mathbf{y}}$, $\hat{\mathbf{z}}$ along the X, Y and Z axes, expressed in some inertial frame (the fixed frame of the Earth, say; unlike the X, Y, Z frame which is in motion). See Fig. 1.

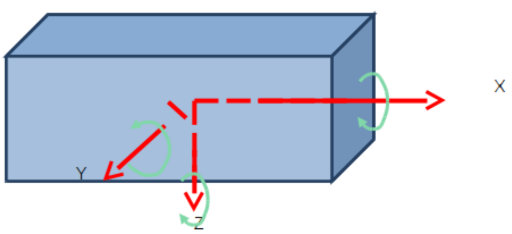

Figure 1: Coordinate system embedded in the moving body.

If the Earth's magnetic field is $\mathbf{B}$ in that same inertial frame, then the magnetic field measurements made by the magnetometers are given by the projections of the target axes onto the Earth's magnetic field:

$$[m_x \; m_y \; m_z] = \mathbf{B} \cdot [\hat{\mathbf{x}} \; \hat{\mathbf{y}} \; \hat{\mathbf{z}}] \, .$$

The rate gyros provide measurements of the rates of rotation about the body axes:

$$\left[\dot{\hat{\mathbf{x}}} \; \dot{\hat{\mathbf{y}}} \; \dot{\hat{\mathbf{z}}}\right] = [\hat{\mathbf{x}} \; \hat{\mathbf{y}} \; \hat{\mathbf{z}}] \times [\omega_x \; \omega_y \; \omega_z] \, .$$

Typical measurement examples for the gyroscope rates and magnetometer fields are sketched in Figs. 2 and 3 below.

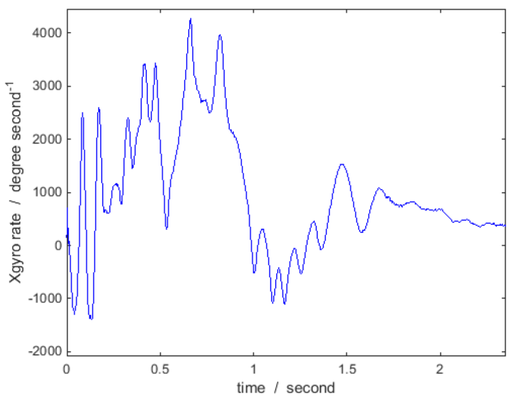

Figure 2: Rotation rate of the air vehicle body as measured by the x axis gyro

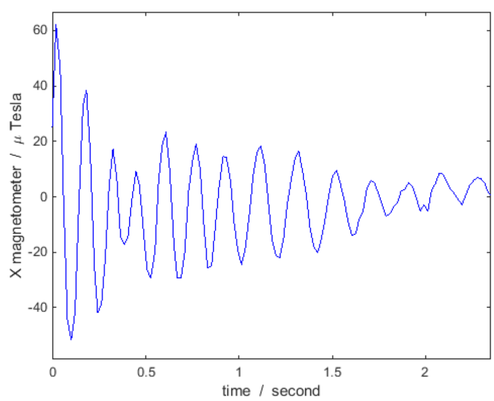

Figure 3: Magnetic field observed by the air vehicle body as measured by the x axis magnetometer

The problem to be addressed is to find the optimal estimate of the flying body's orientation as observed in the inertial (Earth's) frame, consistent with the measured gyro and magnetometer data. This problem comes with several flights of several different vehicles, allowing methods to be checked with different sets of data. The method of solution is not constrained but the aim is:

- For the method used to be as unbiased as possible.
- The algorithm should be as efficient (fast) as possible
- Outputs should ideally be expressed in terms of yaw, pitch and roll angles of the body, (for example) as measured in a North East Down Earth coordinate system.

It can be assumed that we know the Earth's magnetic field at the location, expressed in a North East Down coordinate system:

$$\mathbf{B} = [19.621, 0.554, 44.470] \, .$$

However, it may be appropriate to consider that precise value of this field is uncertain or that the sensor calibration is imperfect.

Pre-requisites

This project is offered as a MathSys MSc project only with Selex ES as the external partner. The student should be interested in data analysis and should have a strong mathematical background if interested in pursuing the more theoretical aspects of the project. The student will be expected to test their methods on real data. The student should ideally be a UK national (see below).

Additional considerations

The external partner, Selex ES, is part of the Finmeccanica group. It is active in defence, aerospace and security, providing hardware components, systems and services. Selex ES has several locations in the UK but the site relevant to this project is located in Luton making it easy for the student to interact with them. This project is not classified although some details of applications will not be available. This project will likely lead to a follow-on PhD project in the area of optimal target tracking co-funded by Selex ES. Selex ES wishes to be able to offer a job to a successful PhD student at the end of their studies. Therefore a student interested in the follow-on PhD project must be a UK national.