# Proposal for Earth Magnetic Anomaly Navigation

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## I. Topic and Background

The proposed topic of research is navigation using measurements of Earth's magnetic anomaly. Magnetic fields are represented by a continuous vector field with magnitude and direction which permeates through free space. Earth's magnetic field is the field created by the abundant magnetic material within the Earth; this permanent field is perturbed by solar wind and charged particles moving throughout the ionosphere which creates a significant time variation in the field. A magnetic anomaly is a local variation in the Earth's magnetic field caused by geophysical variations present in the Earth's crust. Magnetic materials occur in varying densities throughout the crust which contribute to the overall magnetic field strength at any point in space. Variations in the field due to these features are orders of magnitude less than the total magnetic field strength which is primarily due to the Earth's iron core [3]. The so-called core field is on the order of 40,000 nanoteslas (nT) varying slowly around the magnetosphere [3]. Magnetic anomalies are on the order of 100 (nT) and therefore require more precise instrumentation. A minimum of 10 (nT) of measurement precision is needed to accurately capture the anomaly field. If measurements are made and position-correlated, a map of the magnetic anomaly can be produced. To show just the anomaly affects the core field must be subtracted at every point. The values around the Earth are well modelled by the World Magnetic Model (WMM) [3]. The measurements must also be corrected for time dependent variations such as those created by charged particles in the ionosphere, solar wind, etc.

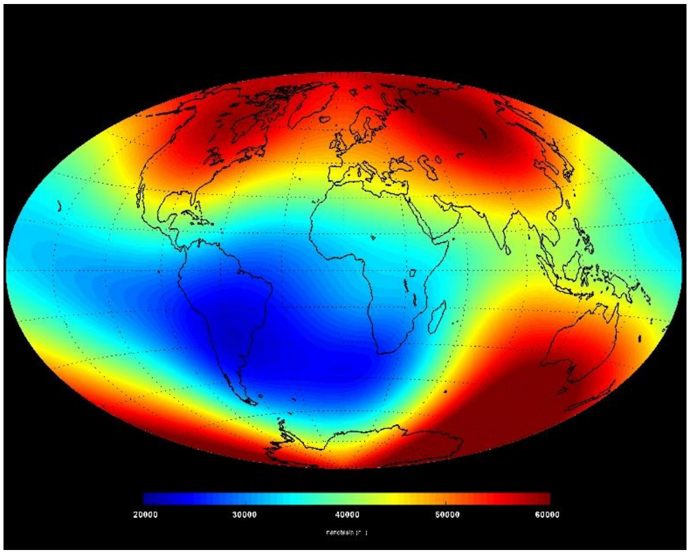

**Fig 1: Earth's Magnetic Field (Wide Perspective)**

If a sufficiently fine map of the magnetic anomaly is available, and precise measurements of the local magnetic field can be made, then the measurements can provide information of the relative position of the sensor. This information can be injected into a position estimation filter in real time or post processed to reconstruct the state. This type of measurement source has a few key advantages over others such as GPS or visual navigation. The magnetic field exists over the entire Earth including over oceans where there are no navigation references. The magnetic field is nearly impossible to interfere with since the power dissipates $\propto \frac{1}{r^3}$ rather than the square of r as with EM waves. This project will study the prospect of navigation using Earth's magnetic anomaly.

## II. Data and Methods

The key data for this project will be the magnetic anomaly map. The minimum information needed is magnetic anomaly field strength and corresponding position over some useful geographic scale. This is generally the toughest part of magnetic navigation since measurement of the field must be made at every position in the field; there is no remote sensing method for collecting this data. Since use for this data are niche (magnetic navigation has not been widely implemented) creating these maps has not been made profitable and so geographic coverage is sparse. Fortunately, the National Oceanic and Atmospheric Administration (NOAA) generates publishes a worldwide map featuring anomaly field strength at sea level and 4 (km) altitude above sea level called the Earth Magnetic Anomaly

Grid (EMAG) 2. This map fuses measurements made from satellite, ship, and airborne magnetic measurements [1] from a variety of data collects. The data is publicly available at the site in [1]. The raw values are plotted below using Matlab.

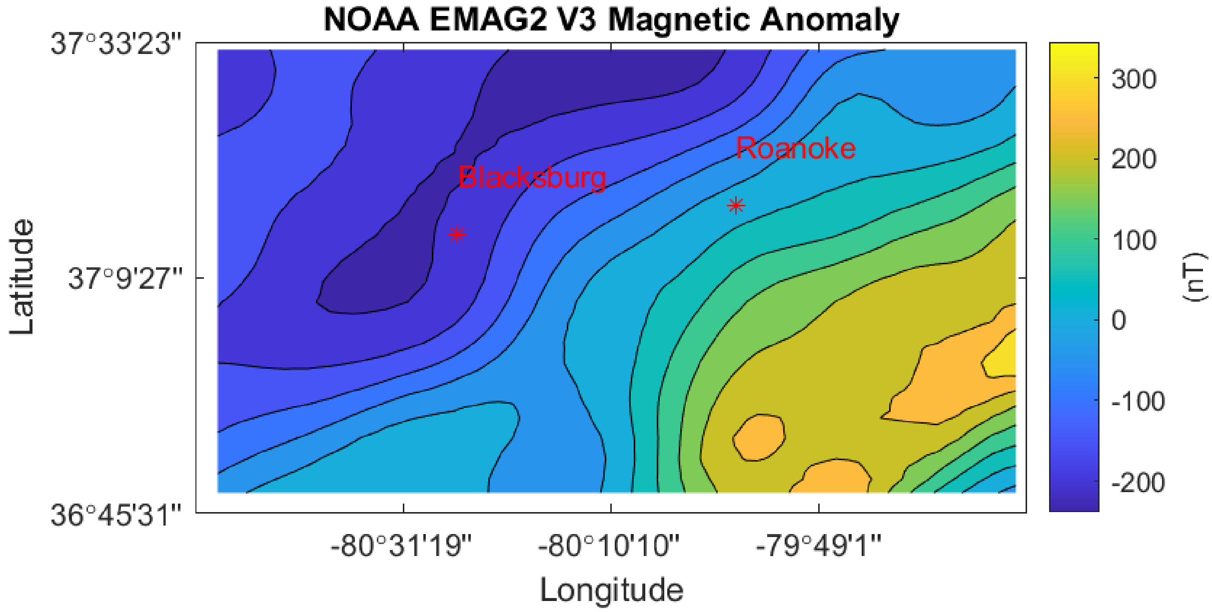


**Fig 2: NOAA EMAG2 Contour Plot**

This contour plot shows the variation in field over a roughly 10,000 ($km^2$) area around western Virginia at 4 (km) altitude. There are nearly 1000 data points for this area from -200 to 300 (nT). Up sampling using some interpolation scheme should produce data sufficient for regional navigation. This data can at the very least be used to validate methods for use with more detailed maps.

A Kalman Filter can be used to estimate position using a model of the measurement [2]. The measurement model will be created to inject the measurements of position (from simulated magnetometer readings and the EMAG2 map) into the filter. There are derivations of this for magnetic navigation studies as well as classical terrain following which uses the same mechanism but with maps of land elevation. The magnetometer model will be the true map values subject to zero bias gaussian white noise.

Measurement prediction

$$\hat{z}(k+1|k) = H(k+1)\hat{x}(k+1|k)$$

**Fig 3: Kalman Filter Prediction step**

## III. Anticipated Outcome

The threshold outcome is position estimates for a simulated trajectory between Roanoke and Blacksburg using simulated magnetic anomaly measurements as the sole measurement. The objective outcome is the same but with measurements subject to error associated with ionospheric and solar interference and methods to account for this error. The tracking performance will be investigated for various run cases and Monte Carlo repetitions. Performance for the EMAG2 dataset should be sufficient for regional navigation but would need to be finer for shorter range motion. One aspect of magnetic (or any map based) navigation is motion over the region; a stationary reading of the field does not provide position information. This will be shown by state estimation plots comparing to the true values along with the covariances on the individual states.

## References


[1] Earth Magnetic Anomaly Grid (EMAG) 2 | National Centers for Environmental Information (NCEI) (noaa.gov)

[2] Estimation with Applications to Tracking and Navigation Theory Algorithms and Software, Yaakov Bar-Shalom

[3] Geomagnetism | National Centers for Environmental Information (NCEI) (noaa.gov)