

What's in the Box? X-ray and EM Hybrid Image Reconstruction

Thomas Anderson-Olson¹, Sean Holman¹, Michael O'Toole¹, Maxim Joseph²
¹University of Manchester; ²AWE Industrial Supervisor

Introduction

This project aims to develop a novel method of joint reconstruction that provides accurate imaging of sealed containers and their contents. The data fusion of electromagnetic signatures together with X ray CT combines two existing methods of non destructive testing that have not previously been considered together. Low frequency EM scanning has the penetration power to examine dense metals in situ whilst also allowing for material identification from the conductivity profile. X-ray CT can provide hard edge boundary information that can constrain the solution. The contents of the containers are assumed to be mixed quantities of various metals, in unknown orientations, such that neither method alone could unambiguously identify them.

Eddy Current Induction Forward Problem

Starting with the Ampere-Maxwell equation, Dodd and Deeds¹ showed that the vector potential can be written as a product of Bessel functions integrated over the spectral modes α . Taking the curl of the vector potential gives the magnetic flux density, in and around the metal.

$$\nabla \times H = i_0 + J_\sigma + \frac{\partial D}{\partial t}$$

$$A_\phi^{(4)}(r, z) = \mu I r_0 \int_0^\infty J_1(\alpha r_0) J_1(\alpha r) e^{-\alpha z} \alpha \left[\frac{2\alpha_1 e^{(\alpha_2 + \alpha_1)c} e^{\alpha_2 z}}{(\alpha - \alpha_1)(\alpha_1 - \alpha_2) + (\alpha + \alpha_1)(\alpha_2 + \alpha_1) e^{2\alpha_1 c}} \right] d\alpha$$

where the complex valued function α_i encodes the diffusion, phase lag and skin depth of the material and depends on the spectral parameter α , the angular frequency ω , the electrical conductivity σ_i and the permeability μ_0 .

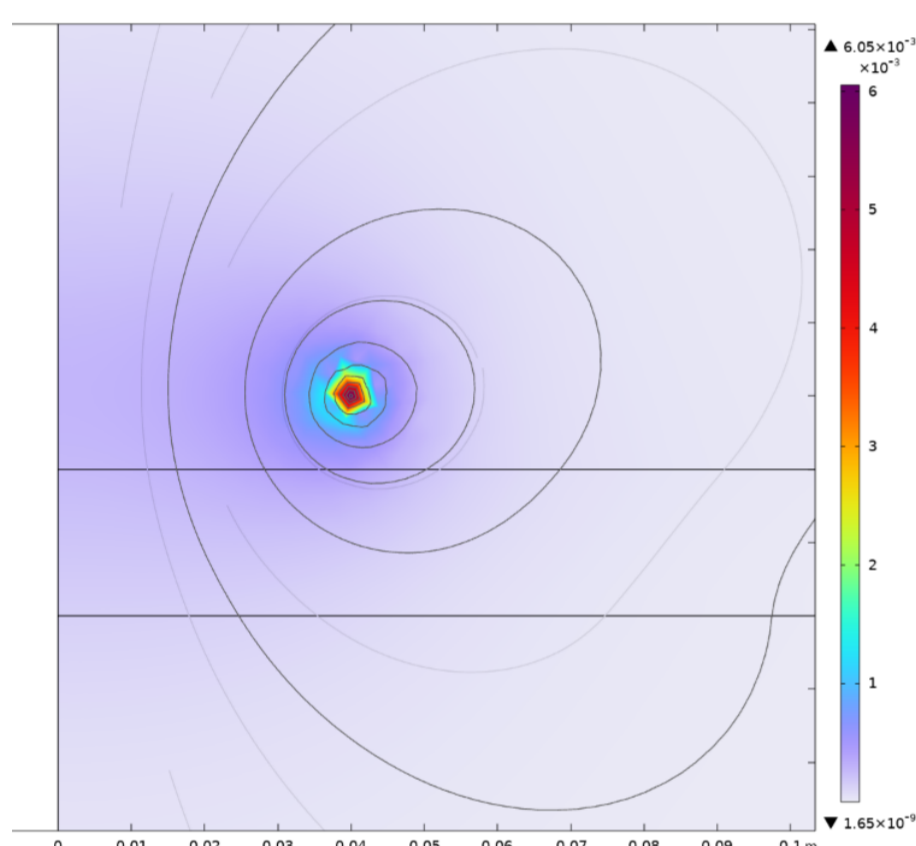


Figure 1 shows the cross section of a 2D axisymmetric simulation in COMSOL multiphysics. The magnetic flux density around an "infinite" metal plate is partly dependent on the conductivity of the material, allowing for identification of the metal based on its conductivity profile.

In this simple set up we have layers of homogenous isotropic material and can solve the above equation, numerically, considering regions above and below the coil, within the metal plate, and below the plate.

More complicated geometries have been considered where this approach, on its own, loses accuracy.

Figure 2 below shows a Nyquist plot for a range of low frequencies and thicknesses of metal plate. Each curve is dependent on the thickness, measurement location and conductivity. You can see how there is an ambiguity when working backwards; 3cm of steel could give the same frequency responses as 1cm of copper.

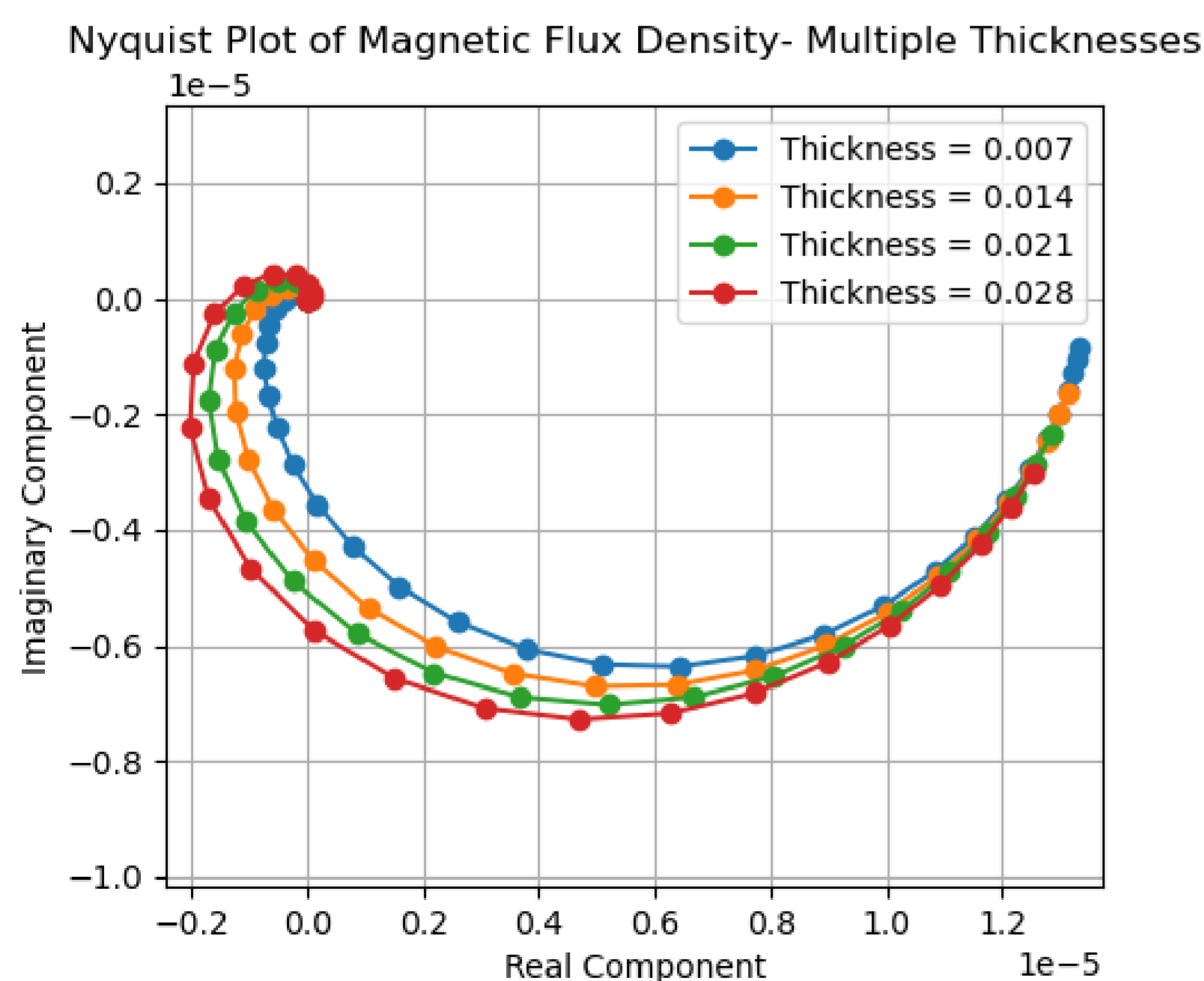


Figure 2: Nyquist plot for range of low frequencies and single metal plate.

References

- ¹ C. Dodd and W. Deeds, Analytical solutions to eddy-current probe-coil problems, Journal of applied physics, 39(6):2829–2838, 1968.
- ² Novel algorithms for magnetic induction tomography with applications in security screening Hiles, A. (Author). 14 May 2020
- ³ Hansen, P. C., Jørgensen, J. S., & Lionheart, W. R. B. (Eds.) (2021). Computed Tomography: Algorithms, Insight, and Just Enough Theory. Society for Industrial and Applied Mathematics.

Existing Work on the Inverse Problem

Previous work on this topic² shows that even with more complicated geometries, it is possible to construct an image based on the conductivity values and measurements of the magnetic field around the object. Figure 3 shows the reconstructed image of a particular geometry that, although picking up some conductivity information, is not especially accurate.

Shape based regularization and colour level set has been used here to optimize and the non uniqueness means that ambiguities cannot be resolved. It is hoped the image can be improved with complementary information.

A joint regularization method, that makes use of edges in the geometry, is hoped to provide the additional constraints that optimize the reconstruction and will likely be a key element of this project.

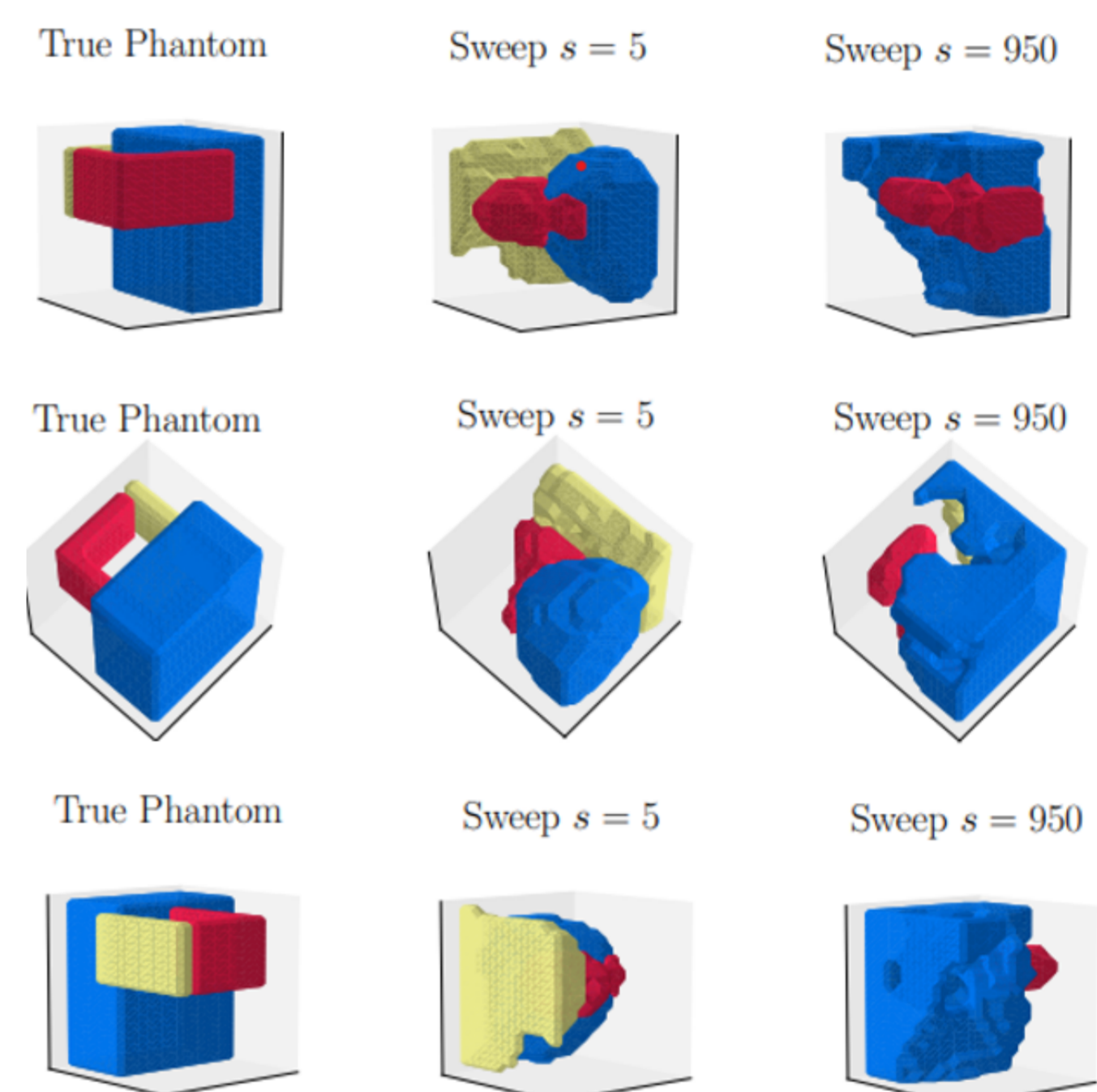


Figure 3: Hiles' work on LK-Color set by conductivity.

Joint Inversion with X-ray CT

By adding additional constraints to the conductivity reconstructions it is hoped ambiguous cases will be resolved and the model will converge for clearer imaging of more complex geometries and materials, such as the example container in figure 3.

X ray CT has its own limitations when imaging high density materials³ but would at least be able to provide limited boundary information that would allow constraints on the positioning and distance from EM detector. It is not known how well this might improve the image.

Figure 4: Example geometry of sealed container with unknown contents.

