Phase unwrapping near metal implants with prior knowledge of the implant geometry

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Target Audience Researchers working in the field of improving MRI near metal implants, particularly fat suppression.

Purpose Techniques for achieving reliable fat suppression near metal implants are currently limited to STIR[1]. The three-point Dixon technique is able to successfully suppress fat in an inhomogeneous B_0 field if an accurate estimate of the phase shift due to the inhomogeneities (φ) can be obtained. Extracting φ from the acquired images will produce a wrapped estimate, φ_w, which lies in the principal period [-π, π] radians. Near metal, the true phase shift will be many revolutions of 2π, so phase unwrapping is required to estimate the true phase shift from the wrapped values. Most existing phase unwrapping techniques assume that the difference in true phase between adjacent pixels is less than π radians in magnitude[2]. Close to tissue-metal boundaries, the phase derivative is greater than π per pixel, so the phase shift is under-sampled. In this work, we propose a new technique to aid the phase unwrapping required for the three-point Dixon method, using prior knowledge of the implant.

Methods Performing phase unwrapping on under-sampled data can be guided with prior knowledge of the phase shift. If information about the size, shape and material of the implant is known, the magnetic field variation (and therefore the phase shift) can be estimated using the relationship derived in [3,4]. In this study, it is assumed that the geometry and material of the implant is known exactly, but we only have approximate knowledge of the 2D position (x, y) and orientation (θ).

The outer surface geometry of a DePuy titanium acetabular cup was obtained using a white light scanner and converted to a 3D STL model, as shown in Fig. 1a. This was rasterised into a 3D array and used as an input parameter to the relationship in [3, 4] to simulate the 'true' magnetic field variation for both titanium and cobalt-chromium (CoCr) implants, at a field strength of B_0 = 1.5T. A 2D slice of the field variation (as shown in Fig. 1b) was extracted and used to model the effect of the implant on the phase of simulated 2D Dixon images with 256x256 pixels and a field of view of 240mm. Zero-mean complex Gaussian noise was added to the Dixon images to simulate an image SNR of 10dB.

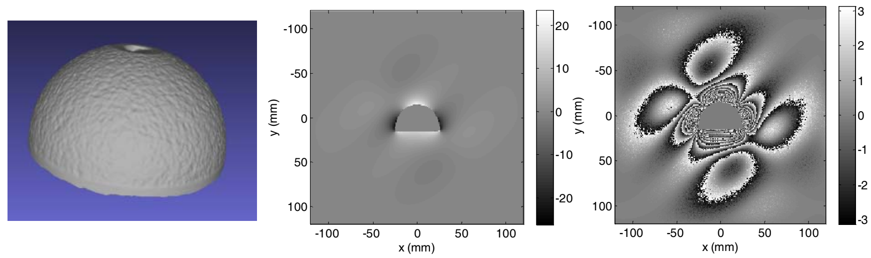

Figure 1: a) 3D STL model of acetabular cup, b) Computed resonant frequency offsets in kHz for a CoCr implant, c) Wrapped phase shift in radians, $\boldsymbol{\varphi_w}$, extracted from simulated Dixon images. Signal loss and distortion have been excluded in this model to enable better visualisation of the phase wraps near the object boundary.

An imperfect model of the phase shift, ψ, is generated by simulating an implant which is offset from the true position of the object (x_t, y_t, θ_t) by Δx, Δy and $\Delta\theta$. Instead of estimating φ from the wrapped values, the phase unwrapping is transformed to estimating the model error: $r = \varphi - \psi$[5]. The contribution by the model is removed before extracting the phase from the acquired images, producing a wrapped estimate of the model error: r_w. If the model is sufficiently close to the true phase, the error is slowly varying and r can be estimated from r_w using existing phase unwrapping techniques.

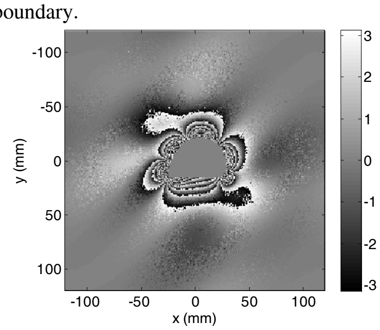

Figure 2: Wrapped model error in radians $\boldsymbol{r_w}$, with imperfect model.

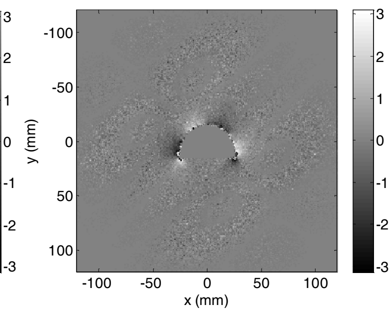

Figure 3: Wrapped model error in radians $\widehat{\boldsymbol{r_w}}$, with adjusted model.

Incorrectly estimating the position and orientation of the model will introduce significant errors, and the derivative of r may be greater than π per pixel. The wrapped phase r_w will therefore contain a significant number of phase wraps, or discontinuities, to resolve. This method translates and rotates the initial model shape using affine transforms to find the model parameter values x, y and θ which minimise the number of discontinuities, E, in r_w. E is obtained from calculating the number of adjacent pixel pairs, vertically and horizontally, whose difference exceeds π radians in magnitude. A coarse grid search is used to find an approximate set of parameters which produce the lowest number of phase wraps. This is refined using a series of grids, each with a finer resolution than the previous. The final refined solution $\widehat{r_w}$, is unwrapped using a technique based on identifying branch cuts [6]. Finally, the unwrapped model error is then added to the adjusted model to estimate the true phase shift, φ.

Results Figure 2 shows r_w for a CoCr model which has an offset of Δx = 5.5mm, Δy = -7.0mm and $\Delta\theta$ = -8.7° from the true position, $x_t = y_t = \theta_t = 0$. The model error has 2362 discontinuities, compared to 5888 in Fig. 1c. Figure 3 shows r_w after adjusting the model using a grid search. The final estimate of the parameters is x = 0.23mm, y = 0.10mm and θ = -0.10° and this image has 90 discontinuities. Table 1 compares the mean number of discontinuities in φ_w with the number in $\widehat{r_w}$, for 10 simulations. These were conducted by randomly generating the initial model offset over the range $\Delta x = \Delta y$ = [-10, 10] mm and $\Delta\theta$ = [-20, 20] °.

Table 1: Effect of using a model on the number of discontinuities in the extracted phase.

	Mean E with no model, $\boldsymbol{\varphi_w}$	Mean E with refined model, $\widehat{\boldsymbol{r_w}}$
Titanium	981	10
CoCr	5842	67

Discussion and Conclusion The proposed method uses a model to significantly reduce the complexity of the phase unwrapping required in the three-point Dixon technique. Preliminary simulation based results are shown. This method should be tested on data obtained from clinical MR images where the Dixon technique is used to suppress fat near metal. Future work will focus on estimating the phase shift with incomplete knowledge of the implant geometry and location in 3D. The effect of image distortion and signal loss and pile-up on phase unwrapping and how prior knowledge can assist will also be investigated.

References

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