# Metallic Implant Reconstruction from MAVRIC $B_0$ Field Maps

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**Target Audience:** Physicists interested in developing MR techniques near metal hardware and clinicians interested in applying them.

**Introduction:** 3D Multi-Spectral Imaging (MSI) techniques such as SEMAC [1], MAVRIC [2], and MAVRIC SL [3] substantially reduce susceptibility artifacts in the presence of metallic implants. These techniques are effective in assessing soft tissue complications directly in the vicinity of orthopedic hardware [4]. The unique broad-spectrum nature of these acquisition strategies exposes a variety of potential applications. Specifically, the MAVRIC family of techniques produces high spectral resolution field maps spanning 20kHz of spectral coverage [3]. Here, we explore an inverse-problem related to these field maps – whereby the field maps are used to back-calculate the susceptibility that generated the measured perturbation field. In essence, the maps are utilized to determine the shape and composition of the imaged metallic implants.

**Theory:** To a close approximation, the static perturbation field generated by a paramagnetic or diamagnetic susceptibility source can be modeled as a superposition of dipoles oriented collinear with the polarizing magnetic field. A means of solving the inverse problem posed here is to: a) identify a selection of voxels as ***potential*** paramagnetic metallic "dipole" sources, and b) determine which of these candidate voxels should ***actually*** be labeled as a given paramagnetic dipole source. In modeling individual dipoles, we can utilize the analytic induced perturbation of a sphere of radius r: $\Delta B_0(x,y,z) = r^3/3*B_0*\chi*(2z^2-x^2-y^2)/(x^2+y^2+z^2)^{\wedge(5/2)}$. This analytic solution holds when the induced perturbation field is much smaller than the applied polarizing field – which is universally a valid approximation in the case of paramagnetic metals. Since we are modeling the voxels as individual spheres, we must also account for a sphere-packing limitation, through which Kepler's theorem leaves us with approximately 75% packing efficiency. To account for this effect, we accordingly adjust the individual dipole moments to provide a net bulk susceptibility estimate.

**Methods:** The steps for a solution to the presented inverse problem are as follows: 1. First, voxels with low signal in a composite 3D MSI MAVRIC image are thresholded out. Then, a region of the image encompassing the implant region is manually selected. The thresholded voxels in this local region will be the search voxels as potential metallic dipole candidates and will be denoted as set ***D*** Next the MAVRIC field map is similarly truncated to the implant region. The voxels above the utilized signal threshold in the composite image are used as source "fitting" points from the field map. Denote these field voxels as the set ***F.*** Note that if a MAVRIC SL image was acquired, the deterministic linear through-plane trend in the field map must be removed prior to further use in the algorithm.

For each potential implant voxel within ***D***, a unit dipolar field is then constructed. A cost function comparing this generated field over the map voxels within ***F*** is then computed, where COST = SUM(||λ*DipoleField(***F***)-FieldMap(***F***)||) This cost function is calculated for differing dipole moments, λ, determined by a pre-determined search criteria for a given implant. For each search point, the dipole moment that results in the lowest cost function value is then assigned to the voxel.

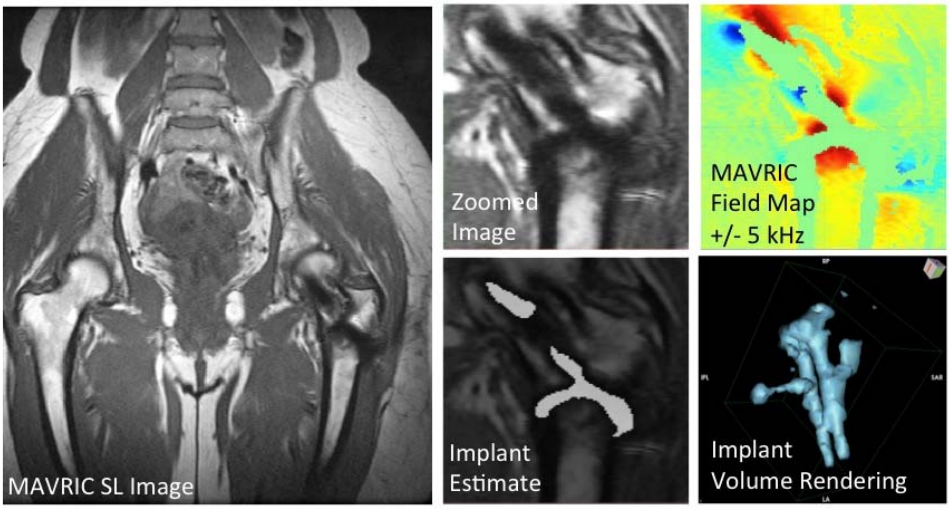


Figure 1: *In-Vivo* demonstration of the field-map inversion algorithm on a hip fixation assembly

**Results:** As an example of the proposed algorithm, we consider hip fracture instrumentation. The applied implant geometry is complex, and requires clear separation of implant components from low-signal cortical bone. Figure 1 shows the results of this implementation of the proposed methods. In this case, the bulk susceptibility of the device was estimated to be roughly 800ppm, which suggests it to possibly be constructed of an alloy of cobalt-chromium. A clearly defined construction of the fixation hardware assembly is shown in the volume rendering.

**Discussion:** We have provided a preliminary demonstration of implant-reconstruction using MAVRIC-based field maps. Other than providing clear visual locations of metallic implant components, there are two immediate additional mechanisms in which such reconstructions could provide clinical value. First, it has previously been shown that even low-artifact 3D MSI sequences have residual signal loss in regions of strong local-field gradients [5]. In the presence of such residual artifacts, it can be difficult to identify actual implant interfaces from artificial signal voids. This is clinically relevant when determining implant or hardware proximity to neurovascular structures or penetration through the tidemark of the subchondral bone. The methods presented here could identify implant boundaries, which, with improved resolution, may prove efficacious in detecting deformation of indwelling hardware or implants as a response to physiologic loads. In addition, implant orientation (relating to particulate wear tendencies) could be determined in an automated fashion, providing device manufacturers insight into potential modification in implant design as a response to this wear.

**REFERENCES:** [1] Lu, MRM 62:66-76, 2009 [2] Koch, MRM 61:381-90 2009 [3] Koch, MRM 65:71-82 2011, [4] Hayter, AJR, 197:W405-11,2011 [5] Koch, Proc ISMRM, 2011, 3173.