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# Off-resonance CorrecTion OPen soUrce Software (OCTOPUS)

**Marina Manso Jimeno**[1], **John Thomas Vaughan Jr.**[1], **and Sairam Geethanath**[1]

**1** Columbia Magnetic Resonance Research Center, Columbia University in the City of New York, USA

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**Software**

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## Summary

`OCTOPUS` is a Pyton-based software for correction of off-resonance artifact in Magnetic Resoance (MR) images. It implements three different methods, it's general to the image acquisition scheme and can be run in the browser, making it a very flexible and customizable tool.

## Statement of need

Off-resonance is an MR artifact whose source can vary from field inhomogeneities, to differences in tissue susceptibilities and chemical shift (Noll, Meyer, Pauly, Nishimura, & Macovski, 1991). These phenomena can cause the phase of off-resonant (not at the resonant or Larmor frequency) spins to accumulate along the read-out direction, which can turn into blurring, geometrical distortion and degradation in the reconstructed image (Luk-Pat & Nishimura, 2001). Images acquired using long readout trajectories and/or at high fields where the field homogeneity is lower, are more prone to this problem. However, such an acquisition scenario also delivers desirable propreties, such as short scanning times, gradient efficiency, motion tolerance and better signal-to-noise ratio (Chen & Meyer, 2008).

Multiple successful off-resonance correction methods have been reported by the literature (Schomberg, 1999). Most of them are based on Conjugate Phase Reconstruction (CPR), a method which counteracts the accumulated phase by demodulating k-space data with its conjugate (Maeda, Sano, & Yokoyama, 1988). From the original CPR, faster and more efficient implementations were developed, such as frequency-segmented CPR (Noll, Pauly, Meyer, Nishimura, & Macovskj, 1992) and Multi-Frequency Interpolation (MFI) (Man, Pauly, & Macovski, 1997).

One can find limited off-resonance correction capabilities within existing packages. Examples are: SPIRiT (Lustig & Pauly, 2010), a MATLAB-based approach for autocallibrated parallel imaging reconstruction; Ostenson's MFI implementation for Magnetic Resonance Fingerprinting (MRF) (Ostenson, Robison, Zwart, & Welch, 2017); FUGUE, a tool for Echo-Planar Imaging (EPI) distortion correction part of the FSL library (Jenkinson, Beckmann, Behrens, Woolrich, & Smith, 2012); and the MIRT toolbox, a MATLAB-based MRI reconstruction package that offers field inhomogeneity correction using iterative reconstruction methods(Fessler, Lee, Olafsson, Shi, & Noll, 2005; Sutton, Noll, & Fessler, 2003). Nylund's thesis (Nylund, 2014) also contains source MATLAB code for fs-CPR and MFI correction of spiral images.

All of the mentioned implementations are highly specific, defined for a particular k-space trajectory, application and/or include a single correction method. These limitations typically lead researchers to adjust their data in an attempt to fit it into the available pipelines or to write their own version of the methods. Either approach results in a significant investment of time and effort and can generate isolated implementations and inconsistent results. Furthermore, most of the available packages are also MATLAB-based, restricting the portability, accessibility and customization of the code (Ravi et al., 2018).

`OCTOPUS` - a Google colab notebook compatible implementation - is aimed at filling this gap in MR off-resonance correction packages. It provides Python open-source code for three fundamental methods (CPR, fs-CPR and MFI). The implementation is independent of the application and the image acquisition scheme, easing its integration into any reconstruction pipepeline. `OCTOPUS` is the first zero-footprint off-resonance correction software given that it can also run in a web browser.

# Short demo

To illustrate the usage of the package we performed in silico numerical simulations using a Cartesian trajectory, a spiral trajectory and a simulated field map. The procedure steps were:

1. Forward model simulation of off-resonance effect on a 192x192 Shepp-Logan phantom (Figure 1.A).
   - Using a Cartesian trajectory (Figure 1.B) and a simulated field map (Figure 1.D) with frequency ranges of -/+ 1600, -/+3200 and -/+4800 Hz.
   - Using a spiral trajectory (Figure 1.C) and a simulated field map (Figure 1.D) with frequency ranges of -/+ 250, -/+ 500 and -/+ 750 Hz.
2. Correction of the results of the forward model (Figure 1.E and Figure 1.F, first column) with CPR, fs-CPR and MFI (Figure 1.E and Figure 1.F, second-fourth columns).

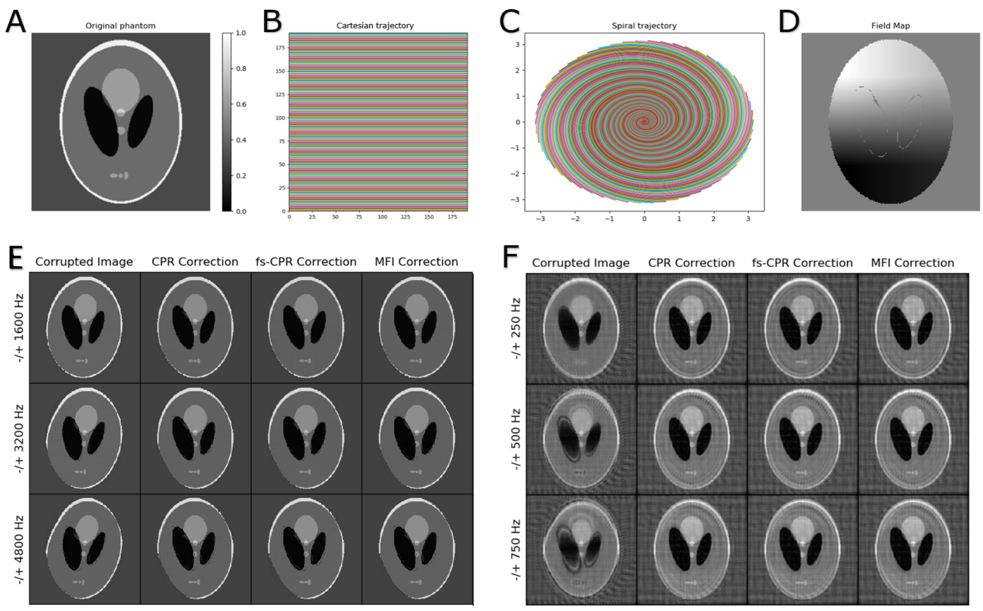


**Figure 1:** Figure 1: A) Shepp-Logan phantom image (192x192). B) Cartesian k-space trajectory. C) Spiral k-space trajectory. D) Simulated field map (192x192). E) Cartesian experiment results. F) Spiral experiment results.

In both sets of experiments, 'OCTOPUS' has successfully corrected the off-resonance induced blurring and/or geometrical distortion. Note that spiral and reconstruction-related artifacts are still present in the spiral simulated images.

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