# Autocalibrated PROPELLER-EPI: intrinsic geometric distortion correction without additional reference data

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**Introduction**

Fast, high resolution $T_2^*$-weighted imaging using *periodically rotated overlapping parallel lines with enhanced reconstruction – echo planar imaging* (PROPELLER-EPI)[1,2] requires precise correction of geometric distortions and resonance frequency shifts. Otherwise image quality is severely degraded by strong blurring. Field map acquisition or measurement of additional echoes for geometric distortion correction, however, comes at the cost of increased measurement time and may hamper the application of PROPELLER-EPI when imaging non-stationary objects or tissues. Abdominal imaging or whole brain imaging is then limited due to the long necessary field map acquisition. In this work, we describe an autocalibrated PROPELLER-EPI image reconstruction method enabling reconstruction of images that are free of blurring without any additionally acquired reference data.

**Theory**

Images acquired with an *echo planar imaging* (EPI) readout are typically geometrically distorted in phase encoding direction. The cause of these distortions are local off resonance effects, $\Delta\omega(x,y)$. With PROPELLER-EPI narrow blades are acquired, which are subsequently rotated around the center of k-space. Due to the periodic rotation each blade has a different phase encoding direction, which leads to differing distortions between the blades. If not corrected, the final image will exhibit strong blurring in those areas, which are off-resonant. By modulating the input data of all blades with a constant frequency offset $\Delta\omega$ along the readout

$$\widetilde{S}(m\Delta k_x, n\Delta k_y) = S(m\Delta k_x, n\Delta k_y)\cdot e^{-i\Delta\omega\cdot t} = S(m\Delta k_x, n\Delta k_y)\cdot e^{-i\Delta\omega\cdot(\pm m\cdot\Delta t + n\cdot T + TE)}$$

the effective resonance frequency on which the image is reconstructed can be changed to $\omega_0 + \Delta\omega$. Here, m and n are the k-space indices $(-N_x/2 \le m \le N_x/2,\ -N_y/2 \le n \le N_y/2)$, $\Delta t$ is the dwell time and $T$ is the time between acquisitions of two neighbouring k-space lines. By discretizing the frequency offset in N steps $\Delta\omega_n$, the local sharpness of the image is gradually changed (Fig. 1), with the maximal sharpness obtained in those areas where $\Delta\omega_n = \Delta\omega(x,y)$. Identification of on-resonant image parts for each $\Delta\omega_n$ would result in a globally on-resonant image free of blurring. Manual identification of image sharpness for each $\Delta\omega_n$ is straightforward but not feasible, whereas automated identification on the other hand poses a challenging and non trivial problem.

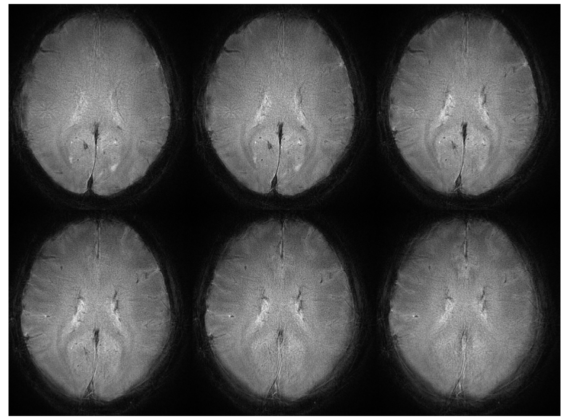

Fig. 1. LAP PROPELLER-EPI images reconstructed on different resonance frequencies. From left to right the frequency offsets applied before PROPELLER-EPI image reconstruction were -15 Hz, -10 Hz, -5 Hz (top row) and 0 Hz, 5 Hz, 10 Hz (bottom row).

**Methods**

To assess the sharpness for a set of images reconstructed with different resonance frequencies offsets $\Delta\omega_n$ we propose the following sharpness detection algorithm:

1. Spatial blurring of all images with a small 3 x 3 pixel averaging kernel to suppress noise contributions.
2. Numerical calculation of 2D gradients of all images to obtain a measure for image sharpness, i.e., high gradients in case of sharp edges and structures.
3. Calculation of the variance of the gradient for each voxel by taking into account a set of weighted neighboring voxels, i.e., the local sharpness around each voxel.
4. Determining the frequency offset $\Delta\omega_n$ for which the variance of the gradient is maximized for each voxel.

Once the frequency offset $\Delta\omega_n$ producing maximal sharpness is found for each voxel the final image can be reconstructed by voxel-wise combination of the sharp image parts. High resolution PROPELLER-EPI images where acquired with matrix size of 320 x 50 voxels per blade on a 3T whole-body scanner. Other acquisition parameters were: TE/TR/FA = 36 ms/700 ms/55°. Seven slices with slice thickness of 2.5 mm were acquired. For comparison high resolution field maps were acquired using a multi-echo gradient echo PROPELLER sequence. Based on the field maps PROPELLER-EPI images were additionally corrected for distortions using a multi-frequency reconstruction[3]. For autocalibrated PROPELLER-EPI reconstruction we discretized the frequency offsets $\Delta\omega_n$ in 100 steps ranging from -50 Hz to +50 Hz.

**Results**

Figure 2 shows two slices reconstructed without any distortion correction (left), with standard correction using multi-frequency reconstruction (middle) and with the proposed autocalibrated PROPELLER-EPI reconstruction (right). The sharpness of the images reconstructed with autocalibrated PROPELLER-EPI is excellent across the entire image with no blurring compared to the images reconstructed with an additionally measured field map.

**Discussion**

Autocalibrated PROPELLER-EPI enables distortion-free reconstruction of high resolution PROPELLER-EPI images without the need of field map acqusition. Besides significantly reducing the pre-scan times, the proposed technique can also be used for abdominal imaging. In the latter case field map acquisition is not a real option since the necessary breath holding significantly limits the available time window for data acquisition. Furthermore, since no static field map is required, autocalibrated PROPELLER-EPI bears the potential to reconstruct distortion free images of moving objects or organs. It is, however, crucial to have available a robust method for detecting image sharpness in the frequency modulated PROPELLER-EPI images. Here, several improvements like incorporating information from both the spatial and frequency domain[4] as well as an implementation of iterative reconstruction are conceivable.

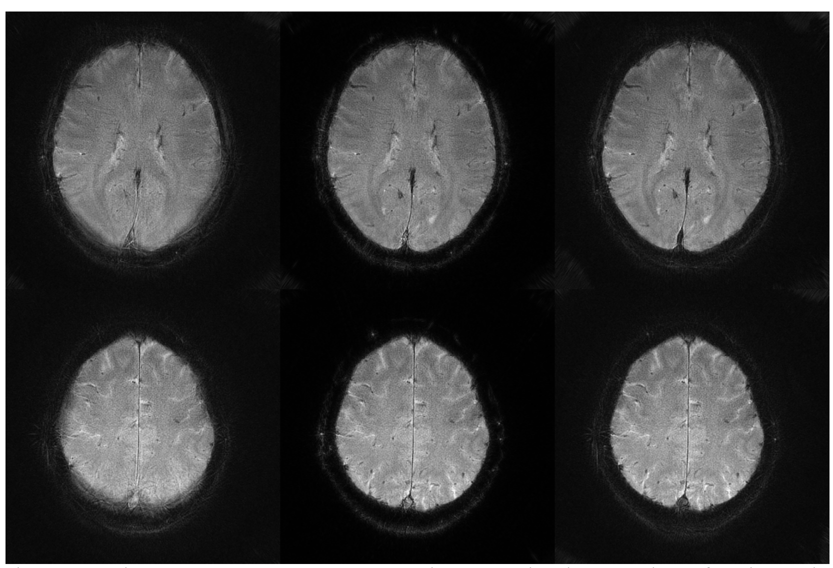

Fig. 2. Two slides (top and bottom) reconstructed without any distortion correction (left), with multi-frequency-reconstruction (middle) and with the autocalibrated PROPELLER-EPI reconstruction (right).

**References -** [1] Wang FN,et.al.,MRM,2005, [2] Krämer M,et.al.,MRM,2012, [3] Man LC,et.al.,MRM 1997, [4] Vu C,et.al., IEEE Image Proc. 2012