Exact Correction of Distortions Due to Static Field Inhomogeneities in Spin Echo Echo Planar Imaging

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Introduction. Inhomogeneities in the applied and induced magnetic field lead to distortions in functional magnetic resonance images, with the effects being more severe for gradient echo images, echo planar readouts, and increased field strength. Increased field strengths are desired for the associated increase in signal-to-noise ratio. Echo planar readouts are useful for their high speed, allowing rapid and repeated imaging of physiologic activity. Gradient echo imaging is used for its sensitivity to the changes in blood oxygenation secondary to changes in brain activity, yet at higher fields brain activity can be detected with much less distortion while being more localized to capillary oxygenation changes by spin echo imaging [1]. Though spin-echo echo planar images (SE-EPIs) have much less distortion than gradient-echo EPIs at any field strength, the distortions in SE-EPI at higher field strengths are significant and interfere with the accurate measurement of brain activity. In this work, we describe the application of the forward/reverse method developed by Chang & Fitzpatrick [2] for the exact correction of distortions in SE-EPI.

Method. The Chang & Fitzpatrick forward/reverse method was developed for standard rectilinear spin-echo imaging. Its success is predicated upon two facts: (1) that distortions due to static field inhomogeneity occur in the opposite directions when the preparation and readout gradients are reversed in polarity and (2) that signal is conserved in the forward and reverse images along every line of the reversal direction. It can be proven that these two principles also apply to SE-EPI, although compared to SE, the distortions in SE-EPI are much more severe in the so-called “phase encoding” (y) direction, given the low effective gradient strength in this direction in an EPI readout. After identifying corresponding edge points in the forward and reverse images, the intensity integrals along the distorted direction of each image are matched to determine the exact mapping of signal intensity and location. Gradient reversal has been used to correct SE-EPI images [3,4], but it appears that these applications may not have taken advantage of the conservation of intensity in SE-EPI. The application of the Chang & Fitzpatrick method does not require shortening TE, which would affect contrast, splitting the data acquisition, potentially affecting contrast or SNR, or computing a phase map, which is prone to errors.

Experiment. Two SE-EPI’s were acquired for each of a phantom and a normal volunteer, one with the k-space trajectory sweeping from $+k_y$ to $-k_y$ (“forward”) and the other sweeping from $-k_y$ to $+k_y$ (“reverse”). The acquisition parameters were TE/TR=35/8000ms, 128x128 imaging matrix, readout bandwidth = 62.5 kHz, 24cm FOV, B_o=3T. For spatial reference, high resolution, comparatively distortion free spin-echo images were acquired with TR/TE = 1000/8 msec, 256x256. The F/R correction method was applied to the forward and reverse SE-EPI’s to produce rectified images.

Results. Figures 1 and 2 show results for the phantom and normal volunteer, respectively. The restoration of the circular nature of the phantom gives evidence as to the efficacy of the method. Furthermore, the high percentage of non-signal producing plastic in the phantom produces large regions of signal voids that could potentially hinder the method, yet the rectification still succeeds. The contours on the forward (2a) and reverse (2b) images of the normal volunteer give an indication as to the severity of the distortion, while the contours on the corrected image (2c) indicate that the distortion is removed.

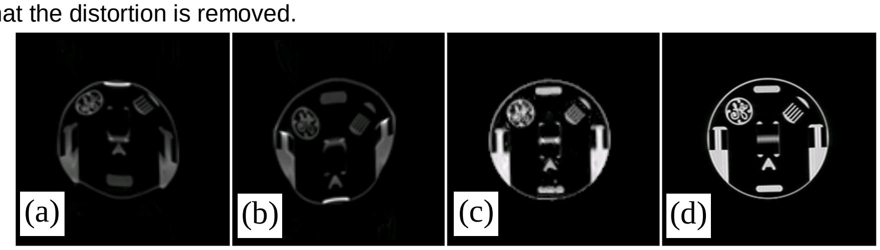

Figure 1. The forward-reverse SE EPI image set of the GE® resolution phantom. (a) Forward SE EPI (b) Reverse SE EPI (c) Corrected image generated with the FR method using a and b (d) High-resolution “distortion-free” SE image.

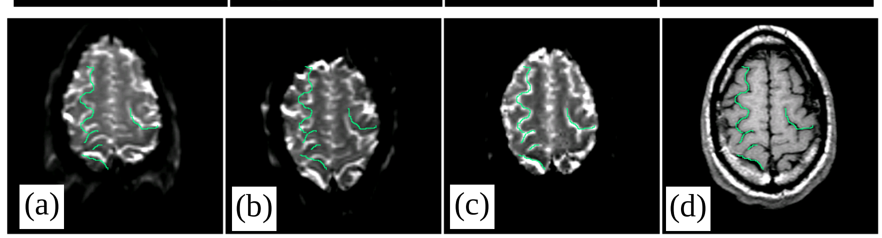

Figure 2. Normal volunteer images. (a) Forward SE-EPI, (b) Reverse SE-EPI, (c) FR corrected SE-EPI, (d) High-resolution “distortion-free” SE reference image. The green lines were drawn on some sulci in the SE reference image, with the lines transposed onto the forward, reverse, and corrected image to show the amount of distortion in the forward and reverse and the accuracy of correction in image (c).

Conclusions. Correction of distortions in spin-echo EPI by means of the acquisition of a forward and a reverse spin-echo EPI is a feasible technique for correcting distortion arising from static-field inhomogeneity. The FR method can be applied as illustrated to an interleaved series of N forward and N reverse SE-EP images to create a series of (2N-1) corrected SE-EP images, which would potentially be very useful for dynamic measurements of physiologic processes at high fields.

References.

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