Segmented Trajectory Correction for Non-Cartesian Imaging with Ramp-up Acquizaiton

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Introduction

Non-Cartesian and rapid imaging sequences are more sensitive to scanner imperfections such as gradient delay and eddy currents. Due to ferromagnetic pole pieces which are attached to the main magnets to degrade the overall performance of MRI magnets, these imperfections are more severe in permanent MRI system than in superconducting and can be a significant impediment towards successful implementation and eventual adoption of non-Cartesian techniques. However, many techniques have modeled such imperfections as gradient delay, B0 or B1 eddy currents and proposed corresponding compensation methods. P.Speier [1] and A.M.Takahashi [2] have proposed correction methods with isotropic and anisotropic gradient delays respectively. P.Gurney [3] has presented an extension of Duyn's [4] method for B0 eddy current measurement by using inverse phase for compensation. As for B1 eddy current，Ethan K[5] has proposed a time-invariant assumption to deal with eddy current induced trajectory deviation and A Lu[6] has further proposed a linear least square fitting method to extract B0 and B1 eddy current terms. In this work we present a method to align peripheral region of distorted k-space and restrict eddy current effects in oblique region.

MATERIALS AND METHOD

The proposed method divides oblique radial acquired k-space into two regions: (1) non-linear region (2) constant shift region [Fig.1]. The first one over covers all oblique acquisition period and endures both B0 and B1 eddy current effect, The second segment is an empirical delay after ramp up, which is not sensitive to eddy current except for a consistent shift in radial direction caused by errors accumulated in earlier segment. The whole k-space with B1 eddy current effect is shown in Fig [3, b]. Our proposed method designs a physical gradient delay scheme to make peripheral k-space realign with idea position [Fig 2.c], and then trajectory in non-lineal region can be measured and synthesized using the method extended from P,Gurney's[3] and Duyn's[4] proposals. We assume B0 eddy current vary linearly with gradient amplitude and B1 eddy current vary linearly with gradient and location respectively [5. On a given axis, Trajectory distorted by B1 eddy current can be measured at two thin slices which are exactly equidistant from Isocenter. and calculated with the following equations:

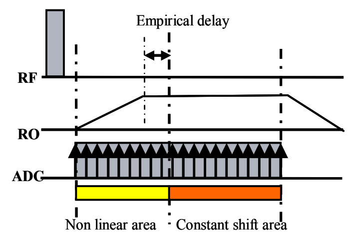

Fig1 Segmentation of one acquisition

$$\Delta\varphi_1 = D_r * 2\pi K(t) + \theta; \qquad \Delta\varphi_2 = -D_r * 2\pi K(t) + \theta;$$

Where K(t) corresponds to real k-space trajectory created by applied gradient and B1 eddy current, θ is B0 eddy current induced phase item. D_r is distance between excited slice and isocenter, In constant shift region, trajectory shifts are caused by accumulated error in non-linear region and can be calculated as following(on a given axis) :

$$k_{shift} = \int_{area1} \left(-\frac{dG}{dt} \otimes e_{g(t)} \cdot x\right) dt = G * \Delta t_{delay};$$

This equation means the accumulated error during non-linear region is proportional to gradient amplitude with a fixed ramp up time. In other words, if we delay RO gradient along a given axis to compensate the error, then a same delay time would measure up the related errors when gradient amplitude reduces. By this way, although the trajectory shifts are different among each radial,[Fig3,b], yet after calibration on 3 physical axis respectively ,trajectory points in segment 2 will be aligned homocentric which simplify reconstruction process. [Fig 3c]

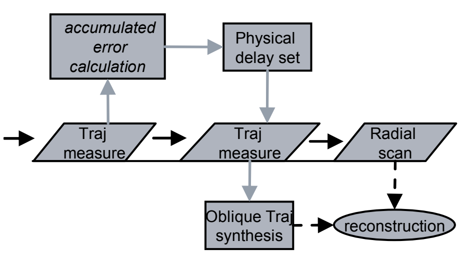

Fig2 calibration and reconstruction process

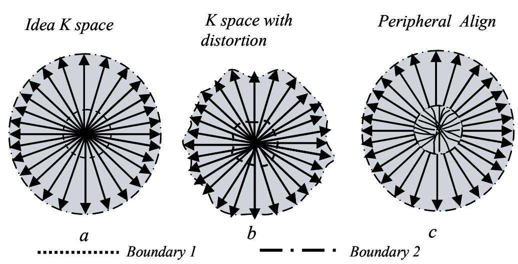

Fig 3, a) idea k-space, b) k-space with eddy current effect c) k-space after gradient delay alignment, samples were increased for covering same range

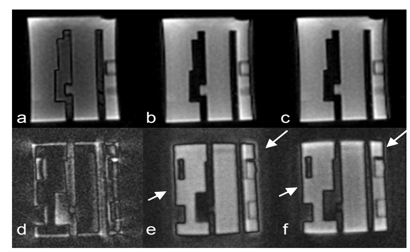

Fig 4, phantom test result: a,b,c with low RO gradient, d,e,f with 5 times increase of RO gradient, a and d reconstructed with no correction, b and e reconstructed with eddy current(b0,b1) corrections c and f reconstructed with segmented k-space corrections

RESULTS AND DISCUSSION

Experiments were performed on a 0.35T SIEMENS C2! Open scanner with a 3D PR readout. The imaging results are shown in [Fig.4]: (1) Image reconstructed with no correction shows obvious signal lost (a,d), (2)with B0 and B1 eddy current correction, reasonable image quality can be obtained (b,e), (3)with segmented k-space trajectory correction, the reconstructed image shows same quality with method 2 in low RO gradient situation(c).and Further improvement in high RO amplitude case (f)

CONCLUSION

An effective approach to align peripheral radial k-space trajectory has been presented. Using gradient delays to compensate accumulated error, eddy current effects were restricted in the non-linear region, the aligned peripheral k-space segment makes image reconstruction more stable and efficient.

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