Anisotropic Field-of-View Support for Golden Angle Radial Imaging

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INTRODUCTION: Radial sampling techniques are often used in dynamic MRI because they are robust to flow and motion, support short echo times, and provide a diffuse aliasing pattern. One drawback is that standard implementations do not support anisotropic field-of-view (FOV). Larson *et al.* provided a simple and intuitive scheme for supporting anisotropic FOV in static radial imaging [1]. In this work, we extend the approach to golden-angle (GA) radial imaging, primarily for dynamic applications.

THEORY: In conventional GA radial imaging, the angles are calculated by $\theta(i) = mod[2i/(1+\sqrt{5}),1] * \pi$, $i = 0,1,2\ldots$ This leads to approximately uniform distributions of the spokes, and therefore approximately isotropic FOV for arbitrary temporal window. When an anisotropic FOV of any convex shape is desired, it can be expressed as a function of the angle $FOV(\theta)$. Since the density of spokes $f(\theta) \propto FOV(\theta + \pi/2)$, the revised GA sampling scheme should maintain $f(\theta)$ corresponding to the given FOV shape, for arbitrary temporal window. Note here $f(\theta)$ is in general not constant any more, and should be determined by the FOV shape. Now consider an angle-normalized space where the angles $\theta' = T\{\theta\}$ and $f(\theta') = 1$, $\theta \in [0,\pi), \theta' \in [0,1)$. In this space, $\theta'(i)$ is calculated by conventional GA sampling scheme for ith spoke. It is then transformed back to the physical k-space to get the angle in real acquisition using $\theta(i) = T^{-1}\{\theta'(i)\}$. Since GA spokes are approximately evenly distributed in θ' space for arbitrary temporal window, $f(\theta)$ is preserved after transforming θ' back to θ. $T^{-1}\{\cdot\}$ can be calculated analytically if possible, or numerically by piecewise linear fitting between θ' and θ.

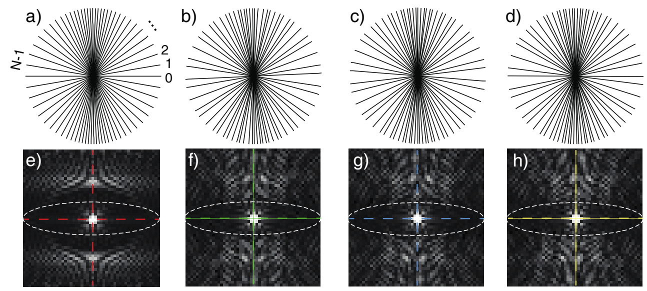

Fig 1. Isotropic resolution examples. a) Fully sampled radial trajectories for an elliptical FOV. b)-d) Three consecutive temporal frames with proposed GA sampling. a)-d) have the same number of spokes. e)-h) PSFs with desired FOVs after 2x gridding (contrast enhanced for illustration).

METHODS: We consider an elliptical FOV (without loss of generality, any convex FOV is possible) with isotropic spatial resolution. First, the fully sampled radial trajectory (Fig.1a) was computed using the Larson method [1]. The angles of the spokes are noted as $\theta_{full}(n)$, $n = [0,1,\ldots,N-1]$, and $\Delta\theta_{full}(n)$ are the angle increments. N is the number of spokes. Second, the index for i^{th} GA spoke in the physical k-space was calculated as $ind_{ga}(i) = N * mod(2i/(1+\sqrt{5}),1)$. Finally, $\theta(i)$ of the i^{th} GA spoke was computed as $\theta(i) = \theta_{full}[A(i)] + D(i) * \Delta\theta_{full}[A(i)]$, where $A(i) = floor[ind_{ga}(i)]$, $D(i) = ind_{ga}(i) - A(i)$.

RESULTS: Fig.1b-d shows the trajectories of three consecutive temporal frames using proposed GA sampling, together with their PSFs after 2x gridding [2] (f-h). The same number of spokes in 1a were used. Sampling density was calculated using the Voronoi approach. Fig.2 compares the horizontal and vertical axes of the PSFs in Fig.1 in log scale. Fig.3 shows the percentage of data needed for elliptical FOV when compared to the isotropic case. Fig.4 shows a slice of banana using a) fully sampled radial b) proposed GA sampling. Images were acquired on a 3T scanner (GE) using radial FLASH with elliptical FOV (Y:X=20:4cm) and isotropic 1mm resolution. 121 spokes were used to reconstruct one image using 2x gridding. Conventional GA with isotropic FOV is also shown for comparison.

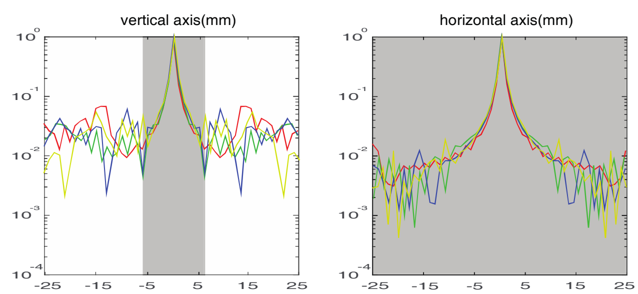

Fig 2. PSF magnitude plots along (left) small FOV and (right) large FOV axes. Colors correspond to Fig.1. The shaded areas are the desired FOV (Y:X=12mm:50mm).

DISCUSSION: Figs. 1-2 indicate that the PSFs of the proposed trajectories are stable (main lobe) and incoherent (side lobes) over time, which are desired for dynamic imaging. Alias-free FOV scales with temporal window size (not shown). Fig.3 demonstrates that the benefit of anisotropic FOV imaging increases with FOV asymmetry. Fig.4 shows that the proposed method can achieve image quality comparable to fully sampled radial acquisition, while noticeable aliasing artifacts can be observed if the same number of spokes are acquired with isotropic FOV.

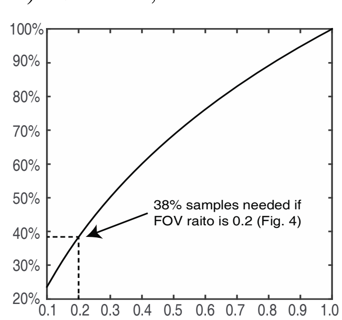

Fig 3. Percentage of data needed for elliptical FOV when compared to isotropic FOV radial sampling. Note the benefits increase with FOV asymmetry.

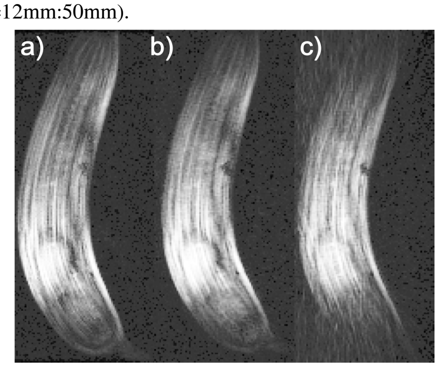

Fig 4. A slice of banana with a) fully-sampled radial, b) proposed GA, c) conventional GA sampling. FOV is elliptical (Y:X=20:4cm) for a) & b) and isotropic 20cm for c). N_r/N_θ = 200/121 for all images. Noticeable aliasing artifacts exist in c).

CONCLUSION: We demonstrate a simple solution to enable 2D anisotropic FOV with GA radial imaging, which can significantly reduce imaging times in many scenarios (abdomen, spine, etc.) where the object dimensions are anisotropic, while still allowing arbitrary temporal window reconstruction. It can be easily extended to 3D stack-of-stars imaging and combined with constrained reconstruction [3].

REFERENCES: [1]Larson *et al*. IEEE TMI 27(1):47-57. [2]Jackson *et al*. IEEE TMI 10(3):473-78. [3] Li *et al*. MRM 72(3):107-17.