One-Shot Fourier Velocity-Encoding with Uniformly-Distributed k-space Trajectory

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Introduction Cylindrical excitation followed by an oscillating readout gradient has been shown to be an effective way of acquiring a velocity distribution in real-time [1]. Higher temporal resolution with less off-resonance effect can be achieved by a partial k-space reconstruction scheme [2]. Variable density trajectories increase velocity resolution [3]. We suggest a uniformly-distributed k-space trajectory for fast and robust image reconstruction without gridding [4] which has been used in conventional Fourier velocity encoding (FVE) methods.

Theory We first use a spiral 2D excitation pulse to restrict imaging to 1D along the x axis to reduce imaging time [5]. An oscillating readout gradient results in a bowtie-shaped spatial-velocity k-space (k_x-k_v) trajectory. Appropriate k-space coverage for partial k-space reconstruction is acquired by shifting this trajectory with a bipolar prewinder [2]. With our new approach, we achieve uniformly-distributed samples along the k_x axis by introducing a flat part in the readout gradient waveform, G_x, as shown in Fig.1. However, this does not increase the scan time much since the usable portion of the k-space trajectory corresponds to only 10% of the total readout time. Since each line of data parallel to the k_v axis is uniformly-distributed, we can perform a simple resampling sinc interpolation to each line. A 2DFT follows to reconstruct the space-velocity (x-v) image.

Because a short readout time is highly desirable to avoid velocity averaging and increased off-resonance effects, we use a triangular gradient waveform with maximum slew rate for the bipolar lobes that make up the readout. Since k_x and k_v are restricted by their first derivative ratios being equal to time, $dk_v/dk_x = t$, we don't have separate control over them. Thus, we set the constant dk_x which is more directly controllable. This will affect dk_v, but does not change the shape of the k-space trajectory much. The FOV_x sets the starting point of the flat region and the maximum k_x sets the ending point. Practically, the FOV_x was chosen for minimal increase in readout time. The tradeoff in choosing FOV_x is that if we set FOV_x large, then the flat region becomes longer and readout time is increased. On the other hand, a small FOV_x involves shorter increase in bipolar lobe duration but needs more spokes to cover the same distance in k_v since we sample the area nearer to the center of the bowtie. Therefore, total readout time increases. Generally, we can get the same k-space coverage with a larger FOV_x with minimal increase in readout time.

Method As a feasibility test, simulations were performed to compare the quality of reconstructed images using $5\Delta x$ by $3\Delta v$ rectangular analytical phantoms in the x-v image domain where Δx and Δv are the resolutions in x-v space. To test the robustness of resampling, we used a shifted rectangular phantom which introduces a linear phase in k-space. FVE waveforms were created to sample k-space with FOV_v = 400cm/s, Δx = 1.67cm, and Δv = 33.3cm/s. The FOV_x was set to 28 cm for conventional one-shot FVE, and 50 cm for the uniformly-spaced version.

Result and Discussion Gridding and resampling of the original samples were performed as in Fig.2. We observed better quality of reconstructed images with the new approach in Fig.3. Although slight ringing exists in the shifted image it is still less apodized.

The new method requires only 1D resampling to generate samples on a Cartesian grid for 2DFT reconstruction. Therefore, this allows a simpler and more accurate reconstruction, which is important in real-time imaging because the number of samples is small, especially in the k_v dimension.

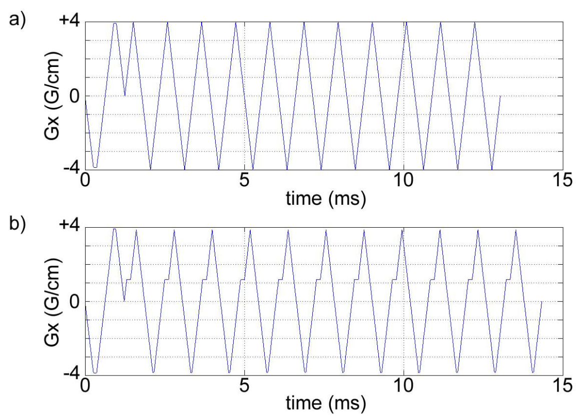

Figure 1: *Prewinder and readout gradient waveforms a) Conventional one-shot FVE b) Uniformly-distributed k-space*

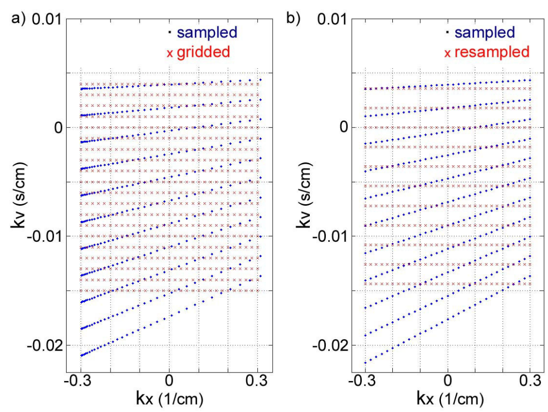

Figure 2: *Gridding and resampling for 2DFT image reconstruction a) Conventional one-shot FVE b) Uniformly-distributed k-space*

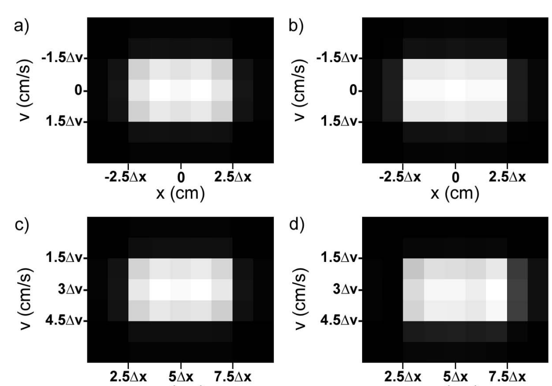

Figure 3: *Simulation results a) Conventional one-shot FVE: centered at origin b) Uniformly-distributed k-space: centered at origin c) Conventional one-shot FVE: shifted to ($5\Delta x, 3\Delta v$) d) Uniformly-distributed k-space: shifted to ($5\Delta x, 3\Delta v$)*

References

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