Edge detection using sub-sampled k-space data: application to upper airway MRI

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Introduction: The detection of tissue borders is of great importance in several MRI applications. Edge detection is typically performed as a post-processing step, using magnitude images that are reconstructed from fully-sampled k-space data. In dynamic imaging (e.g. of human speech, ventricular function, and joint kinematics), tissue borders often comprise the primary information of interest. In such cases, full and uniform k-space sampling may not be the most time efficient approach. In real-time MRI of human speech, high temporal resolution and accurate edge information are both required for a complete understanding of the production dynamics [1]. We propose a rotationally symmetric partial sampling scheme and modified edge detection approach that produces comparable edge maps relative to full sampling.

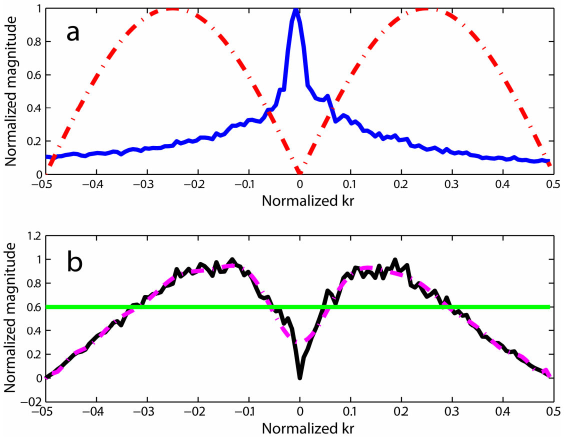

Figure 1: 1D plots of **(a)** k-space signal (blue) and Sobel gradient mask weighting (red). **(b)** weighted k-space signal corresponding to edge information (black), its polynomial fit (magenta), and a threshold level (green) used to determine the sub-sampled region in k-space

Methods: Conventional edge detection algorithms (e.g., Canny [2]) use magnitude images as the inputs and convolve them with gradient masks to determine edge strength and direction. In this work, we perform the gradient operation in Fourier domain, and use that as a guide for appropriate sub-sampling of k-space. The acquired k-space data is directly multiplied by the Fourier transform (FT) of x and y gradient masks. Fig. 1 contains 1D magnitude plots of the data, filters, and product of the two. Note that most of the energy in k-space is concentrated around the k-space origin. After multiplication with gradient filters in k-space, the distribution describes the energy distribution of the edge information. We define sub-sampling schemes that only consider k-space samples where the data is expected to be above a pre-defined threshold, i.e., preserving the k-space region where the most of the edge energy is contained.

Fig. 2 illustrates the reconstruction technique. The absolute values of complex valued Gx and Gy (denoted by |Gx| and |Gy|) were used. This differs from conventional Canny-based edge detection, where Gx and Gy take on real (positive or negative) values [2]. Arctan (|Gy|/|Gx|) produces the angles oriented by edges only ranging from 0 to 90 degrees. In order to discriminate edge directions corresponding to 45 and 135 degrees, sums of diagonally adjacent pixel values along the 45 and 135 degrees are each computed separately, and the one that produces the maximum is chosen as the representative angle.

We applied this method to in-vivo upper airway datasets from a volunteer imaged on a GE Signa EXCITE 3T scanner using a standard single-channel head coil. 2DFT FGRE was used with parameters: TE = 2.3 ms, TR = 5 ms, FOV = 25 x 25 cm^2, and 128 x 128 matrix. The subject pronounced words 'ah', 'ee', 'oh', 'you' during 4-second scans. Data from the 'ee' acquisition was used to estimate the signal distribution in k-space to select the pattern of partial sampling for a given threshold and sub-sampling percentage.

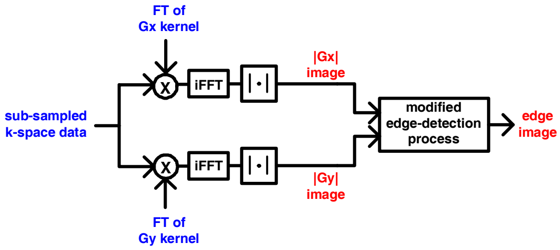

Figure 2: Flowchart of reconstruction / edge detection

Results: Fig. 3 contains resulting images and edge images the case when the subject pronounced the word 'ah'. The appearances of the edge contours are comparable in full and 50% k-space sampling cases. Importantly, the edges of tongue are clearly depicted for all the sub-sampling cases considered. When the full k-space edge image was considered as an ideal edge map, the Pratt figure of merit [3] values for 50%, 40% and 30 % partial k-space were 0.80, 0.75, and 0.69 for a scaling factor of 1.0. Note that detection of edges does not require high-quality magnitude images (reconstructed using FFT).

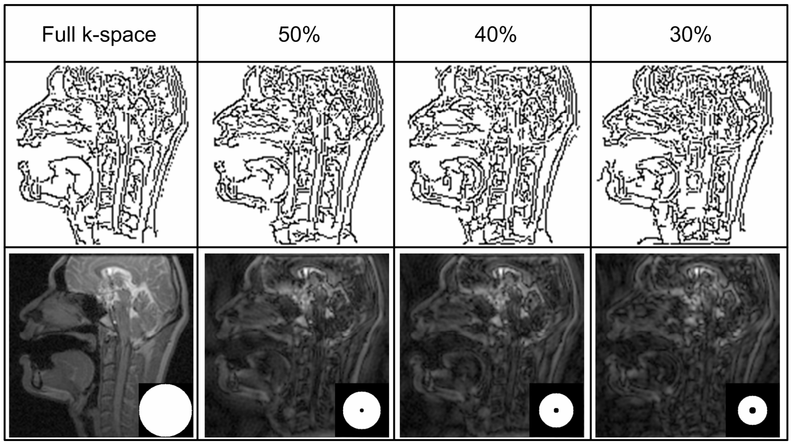

Figure 3: Edge detection from sub-sampled data. **(top)** Edge images. **(bottom)** Images reconstructed using FFT. Inset: k-space sampling pattern. In the case of 50% sampling, accurate tongue boundary information is obtained using the raw data and modified edge-detection process.

Discussion: We demonstrated that in our case of upper airway imaging, 50% k-space sampling can yield edge information comparable to that of the full k-space data. Rotationally symmetric partial sampling can be achieved efficiently using established spiral and spiral-ring trajectories. When uniform density spiral acquisition is used to cover the 50% sub-sampled k-space, only a 34% improvement in time-efficiency is expected due to the inherent oversampling of the k-space origin. Because the k-space origin is not used, we may also overlap the beginning of the spiral with the rewinder of the slice select gradient.

References: [1] Narayanan et al., J.Acoust.Soc.Am., 115:1771-1776, 2004. [2] Canny, IEEE Transactions on PAMI, 8:679-698, 1986. [3] Pratt, Digital Image Processing, New York: Wiley, 1978.