# 2D Matched Filter Acquisition for Improved SNR in Routine Brain Imaging

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**INTRODUCTION** MR images are commonly processed after image reconstruction, e.g. to suppress Gibbs ringing artifacts. In practice, those images are smoothed by a variety of filters, such as a Hamming, cosine or Gaussian window. Furthermore, applications such as inter-subject co-registration, require an additional smoothing step during post-processing.

Following the matched filter theorem, we present how prior knowledge about these filters can also be used for optimizing a regular gradient echo acquisition to maximize the signal-to-noise ratio (SNR) in the final, smoothed images. The approach enables a 2D-matching of the desired filter by combining variable readout line spacing in phase-encoding direction with gradient amplitude modulation in readout direction. This doubles the benefits of a matched filter acquisition compared to sole 1D-matching of the desired smoothing kernels.

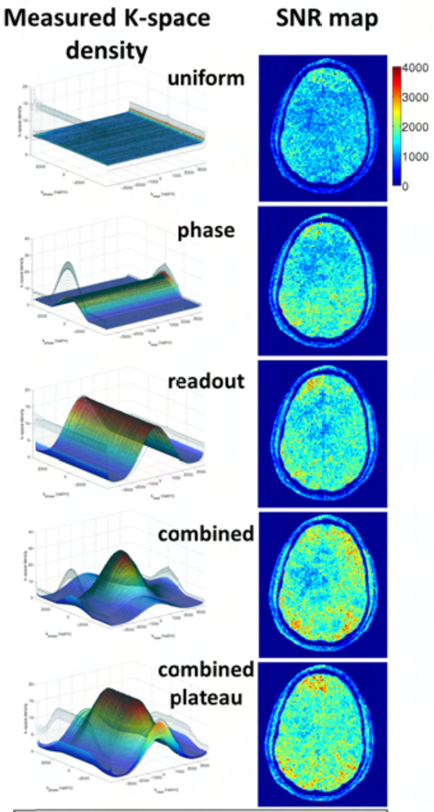


FIG. 1: MEASURED DENSITY WEIGHTING OF K-SPACE TRAJECTORIES (LEFT) AND CORRESPONDING SNR MAP (RIGHT) OF IMAGES AFTER SMOOTHING WITH A (MATCHED) GAUSSIAN KERNEL OF 2 MM FWHM.

**METHODS** The matched filter theorem states that it is optimal to sample signal with its expected frequency response. More specifically, if an effective data weighting (or filtering) $d_{eff}(k)$ is imposed during post-processing, it is preferable to already acquire the data obeying a corresponding sampling scheme. The expected SNR gain depends on the practical match of desired and acquired density $d_{acq}(k)$ and is given by $\frac{1}{SNR^2} \propto \sigma_{eff}^2(k) \propto \frac{d_{eff}^2(k)}{d_{acq}(k)}$.[1] It has been proposed to distribute phase encoding lines in a Cartesian spin-warp experiment unevenly according to the wanted acquisition density[2]. However, this idea is not generalizable to a 2D-acquisition, thus sacrificing half of the possible benefit of a tailored acquisition weighting. For the measurement direction, we therefore introduce a weighting by varying the k-space velocity, i.e. gradient strength $G_{meas}(t)$ throughout the readout fulfilling $\dot{k}(t) \propto \frac{1}{d_{acq}(k)} \Rightarrow G_{meas}(t) \propto \frac{\gamma_{1H}}{d_{acq}(k)}$. For a Gaussian density, an analytic solution can be found as $G_{meas}(t) \propto \exp(\mathrm{erf}^{-1}(At - B)); A, B = const.$, otherwise numerical integration schemes can be used to determine the gradient evolution. Furthermore, boundary conditions with respect to gradient amplitude and slew rate have to be considered for the beginning and end of the gradient time course. This increases the minimum possible TE of this approach somewhat.

Different trajectories with equal overall acquisition duration were tested: Uniform acquisition, phase-encoding weighting only, readout weighting only and 2 variants of combined weighting of readout and phase encoding with a full Gaussian density and a Gaussian with a central plateau of high density. The acquisition resolution was 0.8 mm and the matched filter used was a Gaussian kernel of 2 mm FWHM. All images were acquired in a healthy male volunteer on a Philips Achieva 3T system with body coil excitation and a 8-channel receive head coil. To validate the feasibility and accuracy of the played out, presumably demanding gradient scheme, we used a 2nd order dynamic field monitoring setup with 11 $^{19}F$ NMR field probes[3] to measure encoding and concomitant fields concurrently with image acquisition[4]. We performed iterative image reconstruction using SENSE[5] and calculated the SNR in the resulting images by additional noise reconstructions (10 dynamics).

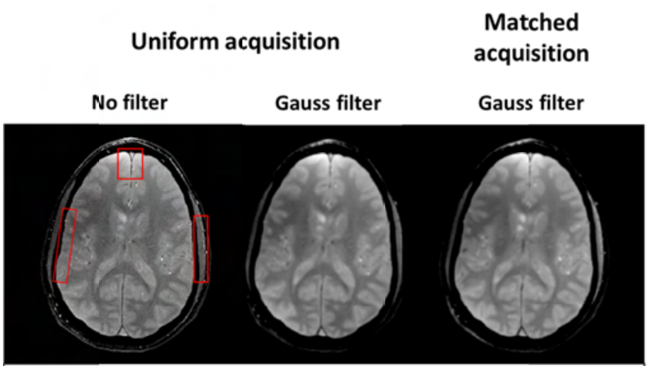


FIG. 2: THE GIBBS RINGING ARTIFACT (LEFT, RED BOXES) IN THE UNIFORM DENSITY IMAGE IS REMOVED USING A GAUSSIAN FILTER OF 2MM FWHM (CENTER). ACQUISITION WITH A MATCHED FILTER TRAJECTORY (RIGHT) YIELDS THE SAME ARTIFACT-FREE RECONSTRUCTION WHILE IMPROVING SNR BY 50 %.

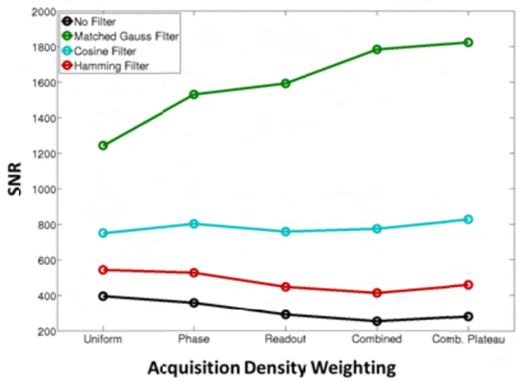


FIG. 3: AVERAGE SNR IN IMAGES ACQUIRED WITH DIFFERENT ACQUISITION WEIGHTING SCHEMES AND AFTER APPLICATION OF COMMON POST-PROCESSING FILTERS.

**RESULTS** The prescribed k-space densities were well reproduced by the gradient system as measured by the NMR field probes (Fig. 1, left). The expected SNR increase affected all parts of the brain (Fig. 1, right) and was about 30 % when using a 1D-weighting trajectory in either phase- or readout direction. This SNR increase nearly doubled to 50 % for 2D-matched trajectories (Fig. 3). Images using monitored, density-weighted trajectories could be reconstructed without artifacts (Fig. 2), and the Gaussian filtering successfully removed ringing artifacts. It is important to note, however, that the post-processing filter has to match the acquisition density for optimal SNR (Fig. 3). If a different post-processing scheme is chosen, the SNR increase drops (e.g. 10-15 % for a cosine filter) or even vanishes (Hamming filter).

**DISCUSSION** We have shown that k-space sampling strategies using a matched filter protocol can improve the image SNR by up to 50 % compared to uniform k-space sampling. The effect degrades with increasing mismatch between acquisition and post-processing filter, but was also shown to give a 15 % increase for a non-matched cosine filter. The approach generalizes to arbitrary density weightings, thus SNR optimal sampling strategies can be obtained for all commonly applied post-processing filters by designing a matched readout gradient modulation and traverse spacing as proposed.

**REFERENCES**
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