# Synthetic Aperture MRI

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## Introduction

Maximization of the image quality in MRI has frequently been accommodated by optimizing the capabilities of the imaging hardware. Nevertheless, any improvement in the image quality of MRI would enhance its clinical efficacy. We propose implementing a novel technique founded upon methodologies from super-resolution (SR) imaging[1] and synthetic aperture[2] (SA) procedures to increase spatial resolution and/or the SNR of MRI.

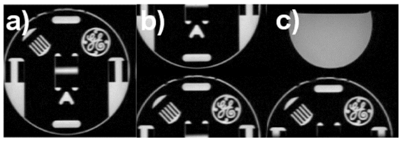

***Fig 1**. a) Unshifted phantom. b) A phase ramp applied after discretization brings no new information to the image. c) The same phase ramp applied before the anti-aliasing filter introduces new information into the FOV. A water bottle, placed on top of the phantom, is brought into the FOV.*

## Background

SR algorithms have recently been applied to MRI to enhance spatial resolution[3,4]. However, the specific mechanism by which this approach adds new information to the MR image with a spin-warp imaging sequence has not been reported, leading some to question the advantage of using SR strategies in MRI over standard interpolation algorithms[5]. We address particular MR data acquisition strategies to derive conditions under which new information *can* be introduced to the image within the SR paradigm.

In SAMRI, we are interested in acquiring multiple low-resolution images (LRI's) with a moving FOV. Due to the Fourier shift theorem, a phase ramp in *k*-space may be employed to produce a FOV shift in the spatial domain (Fig 1). However, the phase ramp may be applied before or after the analog signal is passed through an anti-aliasing (AA) filter and discretized. A FOV shift applied to discrete data provides no new observations of the object[4], and may introduce a wrapping artifact because the discrete image is periodic (Fig 1b). However, if the phase ramp is applied *before* the application of the AA filter, the FOV is moved into a new region of the object, introducing new information into the image (Fig 1c).

To implement SAMRI, a model is derived that implements a point spread function (*psf*), or aperture function, to deconvolve the low-resolution data. Similar to SA techniques, the aperture function is based upon *a priori* phase information. A synthetic high-resolution image (HRI) is formed that has a higher SNR per unit data acquisition time, decreased sample spacing, and is a more accurate representation of the object.

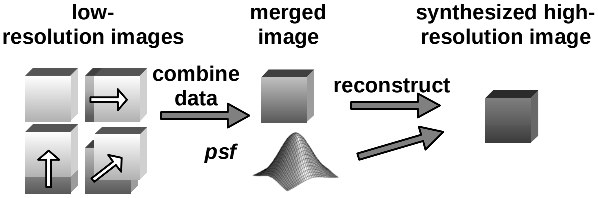

***Fig 2.** Super-resolution image processing. A set of low-resolution images are acquired with a moving FOV. The low-resolution images are merged. The merged data, together with a known psf is used to reconstruct a synthesized high-resolution image.*

## Methods

SAMRI is implemented by first acquiring a set of LRI's with a moving FOV (Fig 2). Once the desired set of LRI's are obtained, they are brought into a merged image that is deconvolved with a known aperture function to obtain a synthesized image with a higher SNR and resolution. The aperture function is calculated using the measurable phase difference between the LRI's. The spatial resolution may also be improved by increasing the spectral extent. We compare these two approaches in terms of the SNR, resolution, and acquisition time (the total time the data is recorded).

Ten LRI's of a phantom were acquired with a 3.0 T, MRI system (General Electric Medical Systems; Waukesha, WI). Another ten LRI's were obtained with a half pixel shift in the readout direction. The LRI's were merged by interleaving their pixels to create ten merged images. A HRI was acquired with twice the number of readout samples and the same FOV. A kernel was derived from the known phase differences between the LRI's, and used to deconvolve the merged images to generate ten synthesized images. The normalized sum of intensity differences (NSID) of absolute values was used to compare the similarity between a single LRI and the downsampled HRI, and the similarity between the synthesized images and the HRI. The above procedure was repeated for a healthy volunteer. SNR's of the synthesized and HRI images were obtained.

## Results

Table 1 shows the average relative acquisition times, SNR's, and NSID's between the synthesized images and LRI's. The SNR ratio of the synthesized image to the HRI was 1.5. In the volunteer data, the SNR ratio of the synthesized image to the HRI was 1.54.

## Conclusions

We have shown that the SNR efficiency and resolution can be improved using SAMRI. Furthermore, by not sampling out as far in *k*-space, SAMRI avoids dephasing artifacts imposed by off-resonance sources while maintaining a small spatial sample spacing. Furthermore, a higher SNR per unit acquisition time has been obtained. A key requirement is that the phase ramp in the frequency domain be applied prior to application of the AA filter, allowing for new observations from the imaged object to be present in each acquisition.

| Image | Res (mm) | Rel mean SNR | Rel acq time | NSID mean |
|---|---|---|---|---|
| LRI | 1.0 | 1.00 | 1 | 0.148 |
| Synthesized | 0.5 | 1.08 | 2 | 0.105 |
| HRI | 0.5 | 0.72 | 2 | NA |

***Table 1.** Mean SNR's, relative acquisition times, and normalized sum of intensity differences (NSID's) between the low-resolution images (LRI's), synthesized images, and high-resolution images (HRI's).*

## References

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