Improving Detection of Micron Size Magnetic Particles Using Linear Phase Ramps

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Introduction. Recently it has been shown that contrast of a magnetic particle is dependent on positioning in voxels, when the resolution is not high enough (1). In the present work the use of linear phase ramps in k-space is explored as a means of improving the contrast of a single particle by phase shifting the image in sub-pixel increments. Such a strategy should also make it possible to determine a particle's position at sub-voxel resolution.

Method. 2 μm diameter iron particles (150 nm thick) spaced 1.28 mm were fabricated on a glass substrate in rows This spacing was chosen to put the particles at different positions in a pixel based on a 100 μm resolution image. The sample was placed in a holder next to a 100 μm layer of water and 2D-gradient-echo images were taken with a resolution of 100 μm. A linear phase ramp in k-space was used to shift the image by fractions of a pixel as attempted for super-resolution experiments (e.g. (2)). Image parameters: TR/TE = 200/12 ms, acquisition bandwidth = 20 kHz, readout direction is left to right. To show how this technique might be used rat olfactory bulb sections have been prepared. Rats were first injected with fluorescent 1.6 um average diameter MPIOs (Bangs Laboratories, Fishers, IN) into the ventricle. Cells in the subventricular zone pick up these particles and migrate via the rostral migratory stream to the olfactory bulb (3). About three weeks after injection, rats were infusion fixed and the bulb was removed and sectioned onto 30 micron thick slices and placed on glass slides. Slides were covered with water and a coverslip (~ 30 μm thick layer) and sealed with vacuum grease to allow for imaging with MRI. Image parameters were TR/TE = 200/8 ms, in-plane resolution = 25 μm. After MRI, microscope slides could be imaged for fluorescence.

Results. Images from a line in the microfabricated particle array are shown in Figure 1. As the image is shifted from left to right it can be observed that the contrast changes depending on whether or not the artifact from the particle is situated close to the edge of a pixel. Figure to shows the signal dropout changes as the particle passes through two pixels. In the most extreme case where the particle is at the corner of four pixels, as in Figure 1E, the signal drop is measured to be 16% compared to a maximum 35% where the particle is at the center of a pixel. The maximum possible change is a four-fold decrease for 2-D and 8-fold for 3-D (1). Figure 3 shows the olfactory bulb histology results. Using an arbitrary 20% threshold below the tissue level we can see two more particles in the zoomed area using series of shifted images over a pixel.

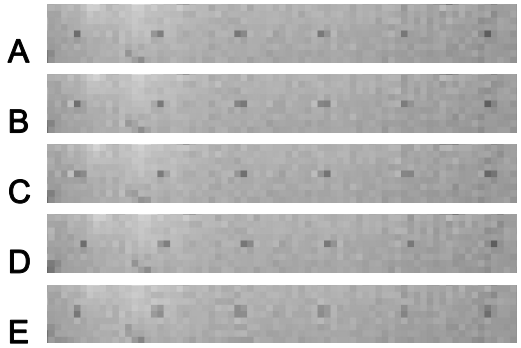

Figure 1. A. Gradient-echo image from particle array. Using a phase ramp the image from **A** was shifted by **B** 0.25, **C** 0.5 and **D** 1 pixel. **E** is an image shift up by 0.5 pixels to show the minimum contrast.

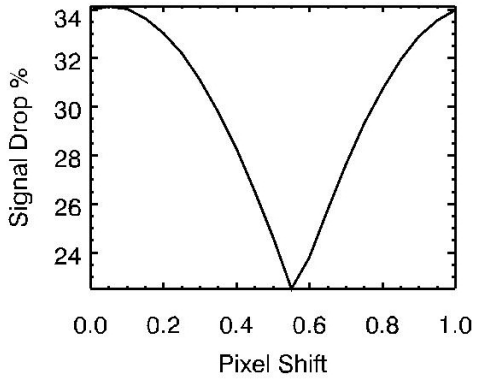

Figure 2. Plot showing the percentage signal drop from the background for the first particle in the row as image is shifted through one pixel. The low point on the curve (least signal drop) corresponds to particle's field spreading through two pixels.

Conclusion. We have shown that it is possible to adjust and improve the contrast of magnetic particles with the application of phase ramps to adjust pixel position. It is expected that this technique will improve particle counts in experiments which use sparse populations of magnetic particles. Furthermore, since the image is shifted by subvoxel increments it should be able to localize particles to sub-voxel accuracy. It is noted that microfabrication proves to be a very useful tool for studying magnetic particles in experiments where high accuracy in position and composition are required.

References

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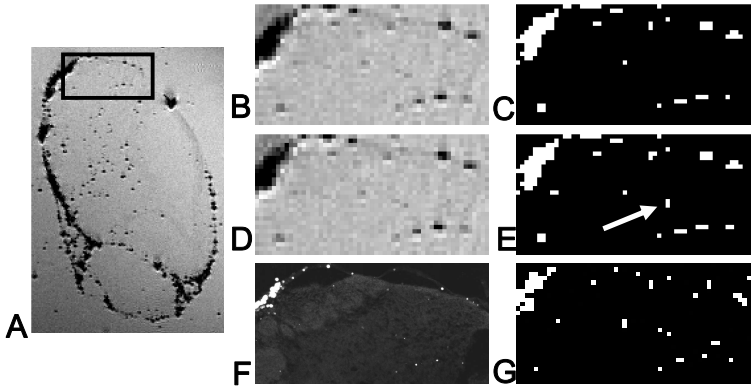

Figure 3 A. MR histology of rat olfactory bulb. **B.** Zoomed area from **A** and **C** threshold mask for particles. **D** image shifted by 0.4 pixels **E** mask showing 2 extra particles below threshold. Particle with the arrow has a 5% contrast improvement. **F** and **G** fluorescence image and mask (resampled to same resolution as image in B) showing reasonable agreement with the MR images