Improving the SNR of Stimulated Echo Acquisition Mode (STEAM) Cardiac Cines

T. A. Yousef[1,2], and N. F. Osman[1,2]

[1]ECE Dept., Johns Hopkins University, Baltimore, MD, United States, [2]Department of Radiology, Johns Hopkins University, Baltimore, MD, United States

Introduction: Stimulated echo acquisition mode (STEAM) technique is widely used in many MR imaging applications. The inherited black blood property is an advantage in functional cardiac imaging. However, it has been reported [1] that the deformation of the heart results in intravoxel dephasing of the magnetization, which leads to significant loss of the myocardial signal. In [2], a new technique was introduced to correct for the through plane deformation. While this technique overcomes the signal loss in the myocardium, it doesn't preserve the uniformity of the SNR in the images—especially on the edges of the measured strain range. In this abstract, a new algorithm is proposed for maintaining a uniform SNR in the STEAM images across the whole deformation (contraction or stretching) range.

Theory: In [2], The STEAM pulse sequence is modified so that after applying the spatial modulation of the magnetization in the through plane direction with frequency ω_m, two images $I_1(x, y, t, \omega_{\min})$ and $I_2(x, y, t, \omega_{\max})$ are acquired at two different demodulation frequencies, $\omega_{\min}$ and $\omega_{\max}$ —determined by changing the gradient in the normal direction during the acquisition. The two frequencies $\omega_{\min}$ and $\omega_{\max}$ are selected as the lower and upper bound of the frequency shift caused by the tissue deformation (*i.e.* $\omega_{\min}$ is selected to correspond to the maximum stretching not exceeded by the myocardium during the cardiac cycle and $\omega_{\max}$ to correspond to the maximum contraction). Then as shown in Fig. 1, the intensity of a pixel (x,y) in I_1 will be maximum at maximum stretching and drop to zero at maximum contraction while in I_2 will have its maximum intensity at the maximum contraction and drop to zero at maximum stretching. By summing the two images (and scaling it with an appropriate factor (fig 2)), the signal loss in both images is recovered in the resulting STEAM image [2].

While this can be valid for objects with small peak shifts around ω_m, the SNR can be highly degraded for large shifts (near the tails of the profile). This can be attributed to the fact that one of the acquired images will be highly dominated by the noise.

To solve this problem, rather than making equal contribution of the intensities of the original images to the final STEAM image, we make the intensity more dependent on the intensity of the image closer to the peak frequency (ω_s).

First, a proper estimate of ω_s is calculated from $\omega_{\min}$, $\omega_{\max}$, I_1 and I_2 using the center of mass method as in Eq. 1:

$$\omega_S = \frac{\omega_{\min} I_1 + \omega_{\max} I_2}{I_1 + I_2} \qquad (1)$$

Then, the intensity estimate I_s at ω_s is calculated using a non-linear interpolation between I_1 and I_2 on the slice profile in the frequency domain. In case of a rectangular slice profile—which results in sinc profile in frequency domain, the following equation is used in the interpolation:

$$I = I_s \operatorname{sinc}(\omega - \omega_s), \qquad (2)$$

Where I = I_1 for $\omega = \omega_{\min}$ and I = I_2 for $\omega = \omega_{\max}$.

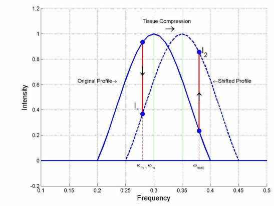


Fig 1: Change in voxel intensity according to the peak shift for a rectangular slice profile excitation.

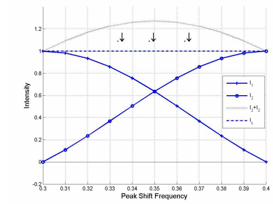


Fig 2: Calculating STEAM voxel intensity I_s using the summation of I_1 and I_2 for the different peak shifts.

Methods: Numerical simulation data was generated for $\omega_{\min}$, $\omega_{\max}$, I_1 and I_2 at different SNR levels by adding different noise levels. Assuming a simulated slice profile at a specific voxel, the harmonic peak profile was shifted in the frequency domain by different degrees within the expected values of voxel deformation. The STEAM voxel intensity was calculated using the proposed algorithm and the resulting SNR were compared to the conventional method.

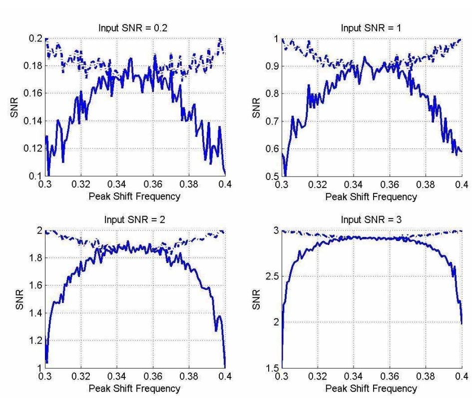
The technique was validated on a normal volunteer using a Philips 3T clinical scanner. Short and long-axis cardiac images were acquired using the pulse sequence described in [1]. The STEAM images were generated using the conventional [2] and proposed method.

Results: Fig. 3 shows the simulation results for the regular and proposed methods for different values of SNR. In the regular method, the SNR achieves its max when the peak shift frequency (ω_s) is at the center frequency between $\omega_{\min}$ and $\omega_{\max}$, then it degrades to minimum at $\omega_{\min}$ and $\omega_{\max}$. In contrast, the proposed method achieves uniform SNR across the peak shift expected range. We can also notice that it gives the same SNR as the input voxels SNR at the edge since the interpolation algoritm, near edges, totally depends on one of the input voxels and ignore the other one since it has pure noise and zero signal. Fig. 4 shows the results in cardiac STEAM images in two series for the regular and proposed method. Note the difference in the voxel intensity between the two series in the low strain areas (e.g. static tissues) and the high strain areas (e.g. the myocardial during contraction in the last two frames) while it remains nearly in the same level for average strain values (the myocardial in the first 2 frames). Also, note that the background noise is slightly suppressed due to the used non-linear interpolation algorithm.

Conclusion: An algorithm is proposed for achieving a higher SNR in STEAM images using the pulse sequence in (2). It also maintains a uniform SNR across different deformation values within an expected range. This enables functional STEAM imaging of the heart without signal loss or SNR being affected due to the tissue deformation.

References: [1] Fischer SE. et al, "Limitations of stimulated echo acquisition mode (STEAM) technique in cardiac applications," Magn. Resn. Med. 34: 80-91 (1995).

[2] Ahmed Fahmy et al, "Correction of Through-Plane Deformation Artifacts in Stimulated Echo Acquisition Mode Cardiac Imaging," Magn. Resn. Med. 55: 404-8 (2006).



the regular (solid lines) and proposed (dashed lines) methods. Note that they nearly have the same SNR in the center (i.e. small tissue deformation). Also, both methods are getting very similar result as the

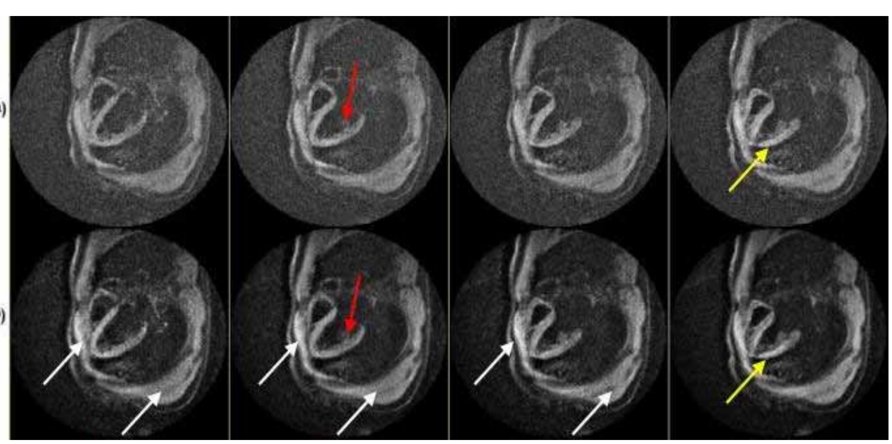


Fig. 4: Generated STEAM images at different 4 cardiac phases at 36, 148, 261, 373ms (in columns) using a) Regular method in [1] and b) proposed algorithm. Note the difference in SNR in both static (indicated by white arrows) and high compression tissues (indicated by