A semi-automatic k-space despiking algorithm for the removal of striping artefacts in MR images

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INTRODUCTION: Image artefacts often cause degradation of the quality of MR images. 'Striping' artefacts are particularly common, and are usually caused by hardware problems such as vibrations, loose connections or improper shielding of the RF coil. This results in brief bursts of radiofrequency (RF) noise, which appear as high intensity 'spikes' in k-space. When Fourier transformed (FT), these cause striping patterns in the image, with the exact appearance dependent on the location of the RF spikes in k-space [1,2]. Striping artefacts can severely disrupt the quality of images, and more importantly affect the quantitative values derived from images.

Our aim was to develop a semi-automatic algorithm for removal of RF spikes from k-space in post-processing, while preserving quantitative information. We applied our algorithm to two applications: cardiac inversion recovery Look-Locker T_1 mapping and cine imaging.

METHODS: Algorithm: The algorithm consists of 2 stages: (i) Identification of the anomalous k-space spikes and (ii) Removal of this anomalous data and replacement with suitable substitute data.

(i) Spike identification was performed using two key characteristics of the spikes: their brief duration in k-space, and their 'random' appearance from one image acquisition to the next, which results in a significant high temporal frequency component [3]. Therefore, a 3D region of interest (ROI) in x-y-t(FT) space, chosen to be outside the object (i.e. in the image background) and weighted towards the edges of t(FT) (i.e. high temporal frequency) will contain information relating to the spikes only, and not to the object of interest. In this way, we can isolate the signal coming from the k-space spikes, enabling selective attenuation. N.B. selection of the ROI is the only non-automatic step in the procedure.

(ii) The spike signal was transformed back into k_x-k_y-t space by 3D inverse FFT and the spikes were removed from the original k-space through division by the 'spike-only' k-space data, weighted by a Gaussian function so that only the edges of k-space were attenuated, leaving the centre unaffected. Specifically, we applied the following correction, derived heuristically following a quasi matched-filter target detection approach [4]:

$$k_{new} = k_{orig} \cdot \left(\frac{gf}{[gf + k_{spike} \cdot \lambda]} \right)$$

where *gf* is a Gaussian function $gf = 1 + \alpha \cdot e^{-(x^2+y^2)/\sigma^2}$ (α= suppression at centre, σ= width of centre of k-space to protect), λ is a parameter defining the strength of the despiking attenuation, and k_{new}, k_{orig} *and* k_{spike} are the despiked, original and spike-only k-space data respectively. After applying this correction, k_{new} was then Fourier transformed along both spatial dimensions to obtain the corrected images.

Applications: The algorithm was implemented in MATLAB R2008b, Student Version (Mathworks, USA) and applied to data acquired at 9.4T (Agilent Technologies, Santa Clara, USA) on the mouse heart using a malfunctioning 39mm volume resonator coil (RAPID Biomed, Rimpar, Germany). Animals were placed supine and a small animal physiological monitoring device (SA Instruments Inc, Stony Brook NY) was used to monitor temperature using a rectal probe, breathing rate using a neonatal apnoea pad and heart rate using two subcutaneous ECG needles during scanning.

The despiking algorithm was investigated on a segmented Look-Locker inversion recovery T_1 measurement (adapted from [5]) (TE/TR(inv)/TR(RF) =1.18ms/13.5s/3ms, 4 phase-encode lines per heart beat, flip angle=5°, in-plane resolution=200µm, slice thickness=1.5mm, matrix = 128x128). To assess whether the quantitative estimation of T_1 was retained, the despiking algorithm was applied to an artefact-free data set and an ROI in the myocardium was used to compare T_1 values before and after algorithm application. The despiking algorithm was also investigated on a cine data set (TE/TR = 1.2/4.5-5ms, cine frames= 20, in-plane resolution=200µm, slice thickness = 1mm). The parameters of the despiking filter were optimised empirically for each application.

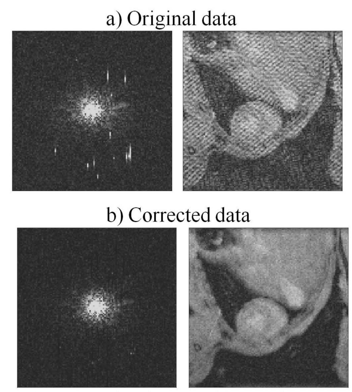

Figure 1: First image of inversion recovery curve from original and corrected data sets are shown here. a) Original k-space and images and b) corrected k-space and image generated using despiking algorithm

RESULTS: Figure 1 demonstrates the effectiveness of the despiking algorithm using the first image from the inversion recovery curve. The RF spikes present in k-space and the resulting stripes in the images are clear in Figure 1a. Figure 1b presents the improvement achieved using the de-spiking algorithm, where the spikes in k-space are removed and the image quality is regained. It was found that T_1 values were maintained when applying the despiking algorithm to an artefact-free data set ($T_{1,\,clear}$ = 1.63 s, $T_{1,algorithm}$ = 1.69 s). The optimised de-spiking filter for the Look-Locker inversion recovery images had the following parameters: λ =3, α= 200, σ=7.

Furthermore, a clear improvement in image quality and delineation of cardiac boarders was observed from application of the despiking algorithm to a severely corrupted cine acquisition (Figure 2). The optimised despiking filter for application to cine images had the following parameters: λ =700, α= 200, σ=15.

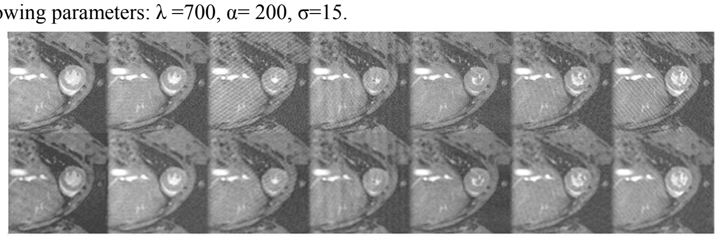

Figure 2: Cardiac cine images demonstrating the improvement in image quality generated by the despiking algorithm. The top row are the corrupted frames and the bottom row shows the same frames after artefact correction.

DISCUSSION AND CONCLUSION: In this abstract, we have presented a simple semi-automated retrospective correction for RF spike artefacts in MR images, which retains quantitative information. Here, this algorithm was applied in the heart, but could also be applied to other organs. This algorithm was shown to effectively remove RF spikes in Look-Locker data sets, while retaining quantitative T_1 estimation. In addition, the improved image quality of cine data sets, is likely to improve the ability to segment the images. These two applications were found to require different optimal filters for the removal of spikes. As apparent from Figure 2, low spatial frequency stripes are more difficult to remove (eg. frame 4), due to the proximity of RF spikes to the centre of k-space. Applying the filter strongly at the centre of k-space (filter parameter α) can reduce the signal intensity of the corrected images, or, narrowing the central k-space protection kernel too much (filter parameter σ) can lead to blurring of images. Future work will investigate whether alternative functions perform better at selectively attenuating the spikes without degrading the desired k-space signal. In conclusion, we have presented a useful tool for the retrospective correction of striping image artefacts in MR images.

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