Assessment of the computational efficiency of perfusion deconvolution algorithms for application to acute stroke

S. Drabycz[1], J. R. Mitchell[1,2]

[1]Electrical & Computer Engineering, University of Calgary, Calgary, Alberta, Canada, [2]Clinical Neurological Sciences & Radiology, University of Calgary, Calgary, Alberta, Canada

Introduction: Numerous deconvolution methods have been proposed for use in quantitative MR perfusion imaging. Three approaches that appear to be robust in the presence of arterial-tissue delays are: circular SVD (oSVD) [1]; reformulated SVD (rSVD) [2]; and Fourier division (FD). There is currently no clear motivation to use one approach over another. Clinical utilization in acute stroke requires quantitative maps to be generated in near real-time. Therefore, our primary objective is to determine which deconvolution approach is the most computationally efficient; our secondary objective is to confirm that all three approaches produce equivalent results.

Methods

Simulated Data: 1024 simulated concentration curves were generated by convolving a gamma-variate arterial input function (AIF) and an exponential residue function with an MTT=3s [3]. 10 trials were performed; the number of timepoints N in each curve was varied from 38 to 128. Independent complex Gaussian noise was added to each signal curve to achieve an SNR=50.

Clinical Data: Perfusion-weighted datasets from 9 acute stroke patients (256x256 acq. matrix, slices=12, N=42) acquired on a 3T MR scanner (Signa, GE Medical Systems, Waukesha, WI) were analyzed before and after zero-padding to N=64. A binary mask was used to threshold noise in the clinical images; masked points were not processed in the deconvolution algorithm but instead set to zero.

Deconvolution Methods: A threshold of P_{svd}=0.2 was used for each algorithm and a time-offset of T_{offset}=N/2s if N<80 and T_{offset}=40s if N>=80 was used for rSVD. A frequency-domain mask was used for FD as in [2] to ensure equivalence between the SVD singular values and the Fourier coefficients. The oSVD, rSVD and FD deconvolution algorithms were implemented in Python 2.4 on a 1.67GHz PowerBook G4 (Apple Computer, Cupertino, CA). An accelerated FD algorithm (accFD) was also implemented in Objective-C for comparison on clinical data. An analysis of variance (ANOVA) was used to compare the time to perform deconvolution on each simulated curve and a single slice of each clinical volume. The deconvolved curves from each algorithm were compared in terms of the mean-square error, MSE = $\sum(R'(t)-R(t))^2/N$, where $R'(t)$ is the deconvolved curve and $R(t)$ is the "true" simulated curve.

Results: We confirmed that oSVD and FD produce equivalent results in terms of MSE for all N as expected since the approaches are mathematically equivalent [4]. rSVD had a slightly higher MSE than oSVD and FD for N<=48 but gave similar results as oSVD and FD for N>48 (not shown). The simulation results showed a rapid increase in computation time with N for oSVD and rSVD and a much slower increase for FD (Figure). There was no significant difference in the average execution time for a clinical image (N=42) between FD and oSVD (p>0.8); however, rSVD was significantly slower than FD or oSVD (p<0.01). For the zero-padded clinical data (N=64) the average time to deconvolve one slice using FD (2.5±0.1s) was significantly shorter (p<0.0001) than with oSVD (5.8±0.9s) or rSVD (6.0±0.9s). There was no significant difference in execution time between rSVD and oSVD (p>0.6). accFD (0.23±0.01s) was over 20 times faster than either of the SVD algorithms.

(a) *(b)* *(c)*

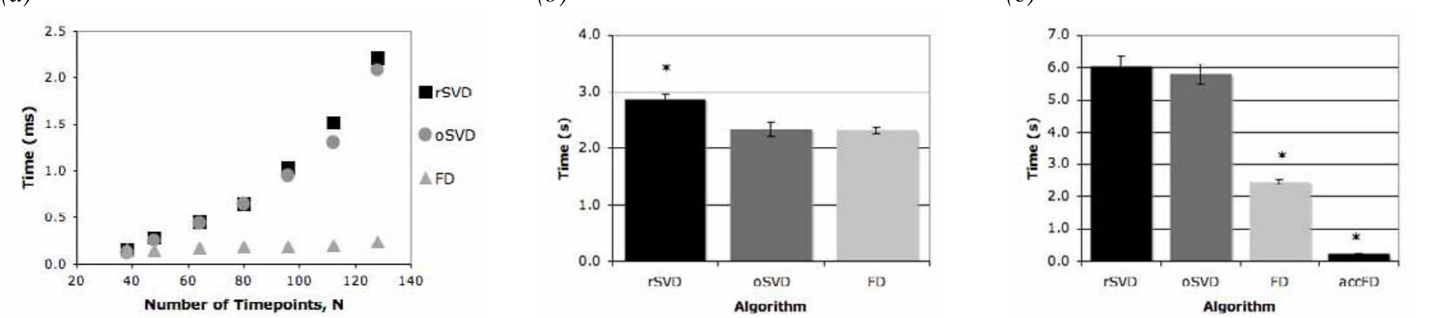

Figure: *Simulation results show that the average execution time for both rSVD and oSVD increases rapidly with number of timepoints, N, while the execution time for FD remains approximately constant (a). The average time to deconvolve a clinical image (N=42) is significantly longer using rSVD than with either oSVD or FD (p<0.01) (b). When the clinical data is zero-padded to N=64 the average time to deconvolve using FD is significantly shorter than with rSVD or oSVD (p<0.0001) and the accelerated FD algorithm (accFD) is significantly faster than the other three approaches (p<0.0001) (c). Error bars shown are standard error.*

Conclusions: We confirmed that rSVD, oSVD and FD produce similar results but have significant differences in terms of execution speed. FD appears to be the most efficient approach when the number of timepoints N>=48 while oSVD is most efficient when N<48. Our results suggest that FD should be used over the algebraic SVD approaches for clinical applications when N>=48. The accelerated FD may allow near real-time perfusion deconvolution for clinical applications.

References

[1] Wu, O *et al. Magn. Reson. Med.* 50:164-174 (2003). [2] Smith, MR *et al. Magn. Reson. Med.* 51:631-634 (2004). [3] Ostergaard, L *et al. Magn. Reson. Med.* 36:715-725 (1996). [4] Trussell, HJ. *Advances in Computer Vision and Image Processing* 1:265-316 (1984).