A novel pixel-by-pixel texture analysis technique improves frequency resolution of local MS spectra

S. Drabycz[1], and J. R. Mitchell[2,3]

[1]Electrical & Computer Engineering, University of Calgary, Calgary, Alberta, Canada, [2]Clinical Neurosciences, University of Calgary, Calgary, Alberta, Canada, [3]Radiology, University of Calgary, Calgary, Alberta, Canada

Introduction

Previous studies have demonstrated that local spectral analysis using the polar S-transform (PST) [1] can help discriminate between normal-appearing white matter (NAWM) and active as well as inactive multiple sclerosis (MS) lesions on MR images [2-5]. The area under the low-frequency portion of the spectrum (low-frequency energy, LFE) has been used to quantify the spectral differences [3,5]. The PST is calculated by computing the spectral amplitude of each frequency for every pixel in an image and then summing in radial bands to obtain one-dimensional local spectra that describe the power at each spatial frequency (the "texture") for each pixel. However, the very large number of computations required for even moderately sized images relegates the PST to a region-of-interest (ROI) approach. This has the undesirable effect of reducing the resulting spectral resolution by a factor of n/N where n is the size of the ROI and N is the size of the image. Furthermore, the resulting spectra may not be inverted to reconstruct the original signal. Here we introduce a novel spectral analysis technique that uses circularly symmetric windows in the frequency domain to reduce the number of computations by a factor of N. We average the contribution of each complex spectral contribution, thereby producing a complex, and fully invertible, 3D local frequency domain. Furthermore, our new method provides complete spectral resolution.

Methods

We tested our new spectral analysis technique on a relapsing-remitting MS patient (age=46) imaged on a 3T MR scanner (Signa, GE Medical Systems, Milwaukee, WI). Axial T2-weighted (TR/TE=5000/98ms) images were obtained (FOV=22cm, matrix size=512x512, slice thickness=5mm, 7mm gap). A large peri-ventricular lesion and a region of NAWM were identified by a neuroradiologist. Local spectra were generated using the PST [1] for ROIs of size 32x32 and 64x64, located within a region of NAWM and a lesion, respectively. A pixel-by-pixel analysis was also performed using our new technique, which we denote as the RST. For both approaches, we averaged together the local spectra within a 5x5 region at the centre of each ROI and calculated the LFE as the area under the spectrum from 0.73 to 3.2cm^{-1}.

Results

Fig. 1 shows the local spectra obtained using both techniques. We were able to perform a pixel-by-pixel analysis of the entire image in approximately 3.5 minutes, improving the spectral resolution to 0.045cm^{-1}; a factor of 8 improvement over the 64x64 ROI analysis (0.36cm^{-1}) and a factor of 16 improvement over the 32x32 ROI analysis (0.73cm^{-1}). Our results show that the average LFE values depend on the size of the ROI used for analysis (Fig. 2). Our technique removes this user-dependent factor from the analysis and provides the maximum available spectral resolution. Our new method appears to better resolve peaks in the spectra that are difficult to identify when using the PST (Fig. 1).

Conclusions

We have demonstrated a novel local frequency analysis technique that is suitable for analyzing texture differences in MS. Our approach provides an efficient pixel-by-pixel spectral decomposition of an image. Preliminary results indicate that the spectra and LFE measurements are consistent with those using PST, but further work is required to determine whether the improved frequency resolution will allow us to better identify spectral regions that can be used to characterize MS disease progression.

References

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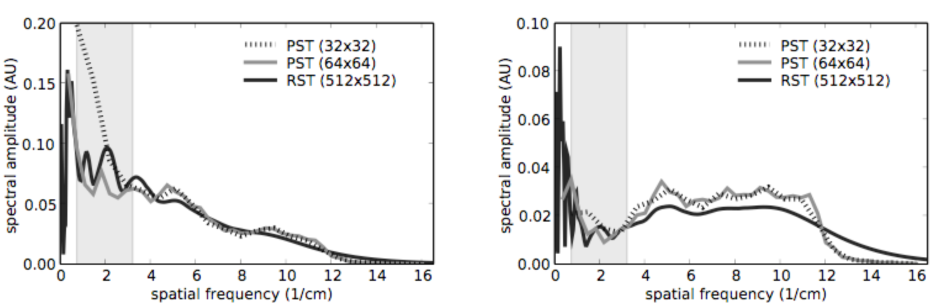

Fig. 1. Average local spectra for a 5x5 region in an MS lesion (left) and NAWM (right). The shaded area indicates the region where LFE is calculated (0.73 to 3.2 cm^{-1}). Our new approach improves spectral resolution by a factor of 8 over the 64x64 PST analysis and by a factor of 16 over the 32x32 analysis. Our method also resolves and emphasizes peaks not obvious in PST analysis.

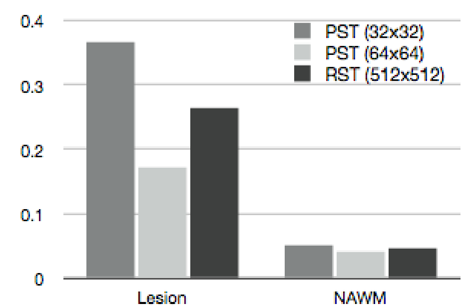

Fig. 2. The average LFE values from PST and our new method, averaged over a 5x5 region in an MS lesion and NAWM. The numbers in brackets indicate the size of the ROI analyzed.