Separation of Signal and Noise in Dynamic MRI Data using the Kolmogorov-Smirnov Test

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TARGET AUDIENCE: Imaging scientists and researchers interested in automatically classifying signal and noise.

PURPOSE: To determine whether the Kolmogorov-Smirnov test can distinguish signal from noise in dynamic MRI.

METHODS: A female athymic nude mouse was injected subcutaneously with trastuzumab-resistant BT474 breast cancer cells. Once the tumor reached approximately 250 mm^3 the mouse was catheterized and DCE-MR images were acquired on a Varian 7.0 T scanner. The imaging protocol employed a T_1-weighted, gradient echo sequence with TR/TE = 100 ms/3.03 ms, NEX = 2, FOV = 28 mm^2. Data was collected for an acquisition matrix of 128^2. A bolus injection of 120 µL of 0.05 mmol/kg Gd-DTPA was given after approximately 3 minutes of baseline collection, and data was collected for 20 minutes after injection for a total of 71 dynamics.

In a dynamic imaging experiment, each voxel time point is a random sampling of an unknown distribution in which the mean indicates the magnetization present, and higher moments indicate noise and error characteristics. The Kolmogorov-Smirnov (K-S) statistical test can test for the equality of two unknown distributions. Voxels containing signal will reflect a different distribution than ones without signal. These distributions are usually assumed to follow a Rician distribution [1] in the magnitude image domain, with the Rayleigh distribution (a limit of the Rician) describing pure noise. For the purposes of the K-S test, we do not need to know the exact underlying distributions; we need only suspect that they are different. In fact, this test is insensitive to the exact properties of the distribution.

To perform the K-S test, all voxels at all time points along the upper edge (away from signal and artifacts) of the image were taken as a lumped noise measurement. The noise sample contained 9088 measurements (128 voxels × 71 dynamics). For each voxel in turn, all 71 dynamic measurements of magnitude were compared to the measured noise distribution using the K-S test. For simplicity, all voxels with a non-zero p-value were considered pure noise, and all voxels with a p-value of zero (i.e., below the machine precision) were labeled as containing signal. For comparison, we also performed the separation using Otsu's method [2] of minimizing the intraclass variance for signal and noise. Two thresholds were used in the Otsu's method approach: the maximum variance cutoff, and 0.2 of the maximum variance cutoff. Mask generation required only 30 s for the entire data set.

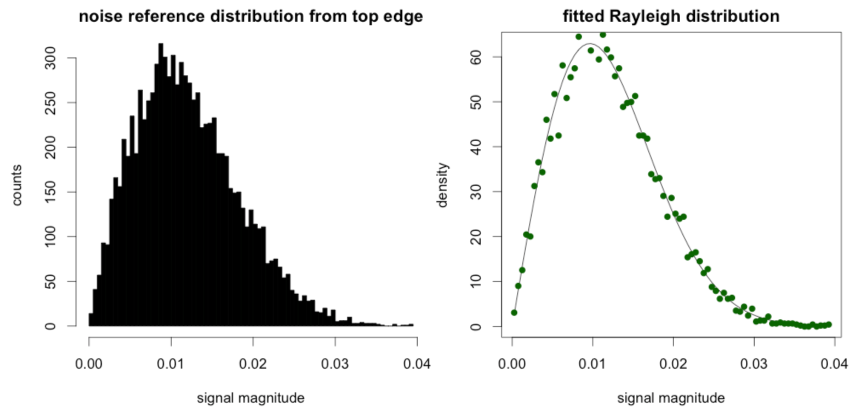

Figure 1: Empirical noise distribution (left) obtained by lumping all voxels along top edge of image at all 71 time points. The fit on the right is a Rayleigh distribution (solid black curve) with the original signal density overlaid in green.

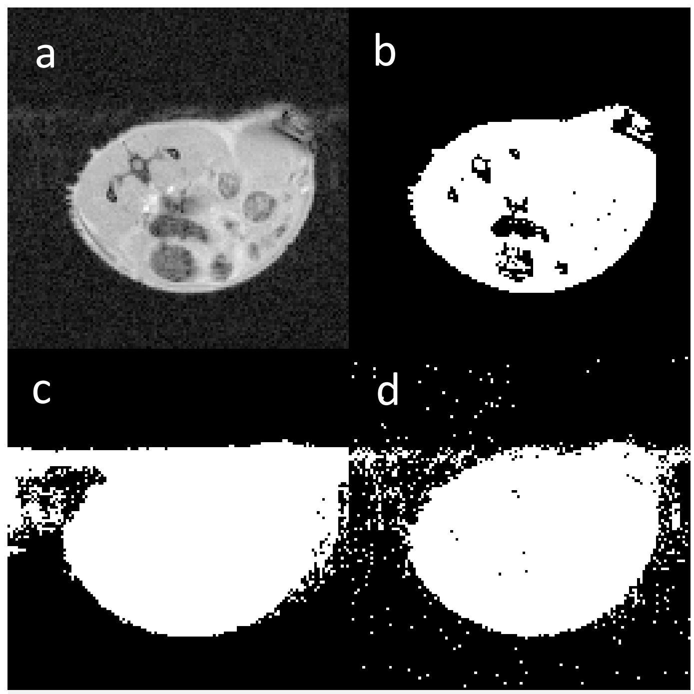

Figure 2: Square root of test image (a) and generated masks (b-d). Otsu's method missed areas of signal inside the mouse (b). Lowering the cutoff arbitrarily to 0.2 of the Otsu threshold captured more of the low-signal voxels, but incorrectly marked air voxels. The K-S test (c) found almost all signal, even the low-intensity aliased power, while ignoring noise outside the imaging volume.

RESULTS: Figure 1 shows the measured noise distribution. It follows a Rayleigh distribution extremely well, as shown by the fit in the right panel. The quality of the fit indicates that we indeed sampled only noise and did not unintentionally capture some signal in the noise sample. This is the reference distribution for the K-S test. Figure 2 shows the square root of the magnitude test image and all signal masks. The K-S test produced the superior mask.

DISCUSSION: The K-S test mask was superior in its accuracy, but it requires multiple (preferably uncorrelated) measurements of the same voxel. Other applications could include testing for contrast uptake by using a pre-contrast signal region as the reference distribution.

CONCLUSION: Preliminary efforts indicate that the K-S test may be an extremely useful method for automatically separating signal from noise in dynamic imaging data, especially when aliased power should be captured but noise should be ignored, such as in compressed sensing [3] reconstructions.

REFERENCES: [1] H. Gudbjartsson and S. Patz, *MRM*, **34**: 910–914, 1995., [2] N. Otsu, *IEEE Trans. Systems, Man, and Cybernetics*, **9**(1): 62–66, 1979, [3] M. Lustig and D. Donoho, *MRM*, **197**: 650, 2007.

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