ECE258B: Multirate Digital Signal Processing. Critique on "*Fast Haar-Wavelet Denoising of Multi-Dimensional Fluorescence Microscopy Data*"

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I. Context

Fluorescence microscopy, a popular live imaging technique, has stringent acquisition-time and phototoxicity contraints. These low illumination conditions create random variations in the photon emission and detection process that manifest as Poisson noise in the captured images. Hence an effective denoising algorithm tailored for Poisson noise is essential prior to visualization and analysis of these images. This algorithm should be efficient with regards to computation time and memory requirements to handle large multi-dimensional datasets common to fluorescence imaging. The technique should also be completely automatic for ease of application and reproducibility of results. The paper [1] being critiqued here describes an automatic, computationally efficient, non-Bayesian multiresolution denoising algorithm designed for Poisson noise.

II. Method description

Denoising of fluorescence images involves minimizing the mean square error (MSE) between the noisy and noiseless images by estimating the statistics of the underlying Poisson process. However, since the noiseless image is unknown, the proposed algorithm minimizes an estimate of the MSE called the Poisson unbiased risk estimate (PURE) [2].

The computationally simple unnormalized Haar wavelet transform (HWT) is first applied to the noisy images as it is the only multiresolution transform which propagates the Poisson statistics in its lowpass channel [3]. Additionally, since the transform is orthogonal, the PURE can be independently minimized in each of the subbands, while ensuring the minimization of the global PURE.

The PURE for a given subband is expressed as a function of the estimates of the noise-free wavelet coefficients ("acceptable" denoising processes) in that subband. The linear expansion of thresholds (LET) strategy [4] is employed to express these "acceptable" denoising processes as a linear combination of elementary denoising processes with only the weights being unknown. These elementary denoising processes are adapted to the local estimates of the signal-dependent noise statistics and involve parameters incorporating the interscale relationships. In addition, correlations between adjacent frames (or slices) in the multidimensional dataset are exploited using a sliding window approach for predicting current subband coefficients from corresponding subbands in neighboring frames. The unknown weights in the LET are computed by minimizing the PURE through a simple linear system of equations and then used to estimate the noise-free wavelet coefficients.

Finally, the noise-free image estimate is retrieved by applying the inverse unnormalized HWT on the PURE-LET estimated noise-free wavelet coefficients.

III. Features and Limitations

The algorithm is very effective in removing Poisson noise in low-intensity fluorescence images and performs comparably to the state-of-the-art *Platelet* approach [5] while being two orders of magnitude faster [3]. It is efficient both in terms of computation time and memory requirements and hence can be used to denoise large multidimensional fluorescence datasets. The efficiency is primarily due to the use of the simple unnormalized HWT and the locally adaptive LET technique. All the parameters of the algorithm are determined entirely based on the image data making the denoising automatic. The algorithm assumes the noise-free wavelet coefficients to be deterministic and hence does not require prior statistical modeling like other Bayesian denoising techniques [6].

In addition to the Poisson noise, fluorescence images can be corrupted by electronic additive white Gaussian noise (AWGN). In such cases, hybrid approaches [7], [8] that model the noise as a Poisson-Gaussian process could perform better. The use of a simple non-redundant unnormalized HWT, requires sophisticated thresholding in contrast to the simple hard or soft thresholding used in other wavelet-based algorithms for removal of AWGN like *SURE-shrink* [9] and *BayesShrink* [6].

IV. Proposed Improvements

One of the main limitations of wavelet-based techniques is that they are more suitable for piecewise smooth signals than for textured signals. Therefore, this algorithm could be generalized by adapting it to other (possibly redundant) wavelet transforms, or even arbitrary linear transforms. However, the exact PURE becomes time-consuming to compute for an arbitrary transform since the unnormalized HWT is the only transform where the global image-domain PURE can be split into independent subband-PUREs [3]. In order to improve the computational efficiency, a first order Taylor series approximation of PURE can be used in practice. In fact, a novel undecimated Haar wavelet PURE-LET estimator [3] has been developed and shown to compare favorably to the state-of-the-art methods.

Also, by extending the noise model to the more general Poisson-Gaussian case, the denoising performance for fluorescence images can be improved. For instance, [7] have assumed a Poisson-Gaussian noise model and have shown better performance than the PURE-LET algorithm for certain fluorescence images. The extended noise model would enable application of the algorithm to a wider range of imaging modalities like MRI and PET.

V. Applications

The denoising algorithm can be applied to any imaging modality where the measurement noise can be modeled by a Poisson process. So far, the algorithm has been primarily applied to multidimensional fluorescence microscopy data. Key ideas from the algorithm (LET in the Haar wavelet domain) have been previously applied for denoising timelapse fluorescence images [10], multichannel images [11] and most recently natural video sequences [12].

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