PhD Thesis Title: Vector Extrapolation and Guided Filtering Methods for Improving Photoacoustic and Microscopic Images

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ABSTRACT:

Photoacoustic imaging is a non-invasive imaging methodology which combines the benefits of optical contrast and ultrasonic resolution. It is applied widely for monitoring tissue health conditions in the fields of cardiology, ophthalmology, oncology, dermatology, and neurosciences. The photoacoustic tomographic image reconstruction problem is typically ill-posed and requires model-based iterative algorithms. The microscopic image analysis of pathological slides is considered as a gold standard for medical diagnosis. To acquire good quality images, one needs to deploy high-cost microscopes, which leads to increase in the cost and hence becomes prohibitive to have utility in low-resource settings. The low-cost microscopic image has low quality due to its inability to acquire focused stacks. The thesis deploys methods based on vector extrapolation and guided filtering to improve photoacoustic and histopathology (microscopic) images.

The limited data photoacoustic tomographic image reconstruction problem is known to be ill-posed and hence the iterative reconstruction methods were proven to be effective in terms of providing good quality initial pressure distribution. Often, these iterative methods require a large number of iterations to converge to a solution, in turn making the image reconstruction procedure computationally inefficient. Two variants of vector polynomial extrapolation techniques were proposed to accelerate two standard iterative photoacoustic image reconstruction algorithms, including regularized steepest descent and total variation regularization methods. It was shown using numerical and experimental phantom cases that the extrapolation methods, proposed in this thesis, can provide significant acceleration (as high as 4.7 times) along with added advantage of improving reconstructed image quality.

Several algorithms exist to solve the photoacoustic image reconstruction problem depending on the expected reconstructed image features. These reconstruction algorithms promote typically one feature, such as being smooth or sharp, in the output image. Combining these features using a guided filtering approach was proposed, which requires an input and a guiding image. This approach acts as a postprocessing step to improve the commonly used Tikhonov or total variational regularization method. The result obtained from linear back projection was used as a guiding image to improve these results. Using both numerical and experimental cases, it was shown that the proposed guided filtering approach was able to improve (as high as 11.23 dB) the signal-to-noise ratio of the reconstructed images with added advantage while being computationally efficient. This approach was compared with state-of-the-art basis pursuit deconvolution as well as standard denoising methods and outperformed them.

Microscopic analysis of pathological slide smears is the gold standard for medical diagnosis, therefore the research community is making efforts towards low-cost image acquisition and automated computational analysis equipment that is especially suitable for developing countries. However, the requirement of the images being very well in focus may not be met with these equipment and thus image enhancement methods that can compensate for this shortcoming gain critical importance. A guided filtering (GF) based approach was proposed for enhancement of out-of-focus microscopic images of human blood smear slides containing healthy and malaria infected Red Blood Cells (h-RBCs and i-RBCs) and PAP smears. Comparisons have also been made with a histogram-equalization method for image enhancement (CLAHE), RIQMC-based optimal histogram matching (ROHIM), modified L_0 based method and the proposed guided filtering method has been shown to outperform these methods. The guided filtering enhanced images lead to better segmentation accuracy and visual quality compared to the native ones. Both these traits are necessary to perform automated diagnosis via image processing and machine learning and hence the method proposed in this thesis work can play an important role towards the goal of universal healthcare.

This thesis work aims at improving the photoacoustic tomography images as well as histopathological microscopic images, where quality of images is an important factor to provide correct diagnosis. The thesis work proposed fast and improved post-processing methods for photoacoustic and microscopic images, especially in cases these images tend to be noisy. The central theme of this thesis work was to improve the quality of photoacoustic/microscopic images obtained in limited/low-quality data scenarios. In microscopy, the low-cost apparatus used for obtaining the microscopic images are often corrupted with noise and provide very limited diagnostic accuracy, especially with automated algorithms. Various methods were proposed and systematically evaluated for performing post-processing of the data obtained using these limited data and low-quality data scenarios for photoacoustic and microscopic images.

References to author publications that relate specifically to the dissertation:

1. **Navchetan Awasthi**, K. Ram Prabhakar, Sandeep Kumar Kalva, Manojit Pramanik, R. Venkatesh Babu, and Phaneendra K. Yalavarthy, "PA-Fuse: A Deep Supervised Approach for Fusion of Photoacoustic Images with Distinct Reconstruction Characteristics," Biomedical Optics Express 10(5), 2227-2243 (2019). [doi: 10.1364/BOE.10.002227]
2. **Navchetan Awasthi**, Sandeep K. Kalva, Manojit Pramanik, and Phaneendra K. Yalavarthy, "Image Guided Filtering for Improving Photoacoustic Tomographic Image Reconstruction," Journal of Biomedical Optics 23(9), 091413 (2018). [doi: 10.1117/1.JBO.23.9.091413]
3. **Navchetan Awasthi**, Sandeep K. Kalva, Manojit Pramanik, and Phaneendra K. Yalavarthy, "Vector Extrapolation Methods for Accelerating Iterative Reconstruction Methods in Limited-Data Photoacoustic Tomography," Journal of Biomedical Optics 23(7), 071204 (2018).[doi: 10.1117/1.JBO.23.7.071204]
4. **Navchetan Awasthi,** Prateek Katare, Sai Siva Gorthi, and Phaneendra K. Yalavarthy, "Guided filter based image enhancement for focal error compensation in low cost automated histopathology microscopic system," Journal of Biophotonics (2020). [doi: 10.1002/jbio.202000123].