**Abstract**

The nonlocal self-similarity (NSS) prior of natural images has been successfully used in many image restoration methods. In this thesis, we investigate the design of new and more effective NSS models for image denoising tasks, especially real-world image denoising. A new dataset to benchmark the study of real-world image denoising method is also established.

To exploit the NSS prior from the external clean natural images, we propose a patch group (PG) based NSS prior learning scheme to learn explicit NSS models from natural images for high performance denoising. PGs are extracted from training images by putting nonlocal similar patches into groups, and a PG based Gaussian Mixture Model (PG-GMM) learning algorithm is developed to learn the NSS prior. We demonstrate that, owe to the learned PG-GMM, a simple weighted sparse coding model, which has a closed-form solution, can be used to perform image denoising effectively, resulting in high PSNR measure, fast speed, and particularly visually pleasing denoising outputs.

The noise in real-world images captured by digital cameras is hard to be characterized by the additive white Gaussian noise (AWGN) model. Therefore, many denoising methods developed under the AWGN assumption may not work well on real-world images. To exploit the information in both external data and the given noisy image, we develop an external prior guided internal prior learning method for real-world noisy image denoising. We first learn external priors from an independent set of clean natural images. With the aid of learned external priors, we then learn internal priors from the given noisy image to refine the prior model. The external and internal priors are formulated as a set of orthogonal dictionaries to efficiently reconstruct the desired image. Extensive experiments are performed on several real-world noisy image datasets. The proposed method demonstrates highly competitive denoising performance, outperforming state-of-the-art denoising methods including those designed for real-world noisy images.

We then investigate how to utilize solely the internal NSS of noisy images for real-world image denoising task. To this end, we propose a multi-channel (MC) optimization model for real color image denoising under the weighted nuclear norm minimization (WNNM) framework. We concatenate the RGB patches to make use of the channel redundancy, and introduce a weight matrix to balance the data fidelity of the three channels in consideration of their different noise statistics. The proposed MC-WNNM model has no analytical solution. We reformulate it into a linear equality-constrained problem and solve it via alternating direction method of multipliers. Each alternative updating step has a closed-form solution and the convergence can be guaranteed. Experiments on both synthetic and real noisy image datasets demonstrate the superiority of the proposed MC-WNNM over state-of-the-art denoising methods.

We also develop a trilateral weighted sparse coding (TWSC) scheme for robust realistic image denoising. Specifically, we introduce three weight matrices into the data and regularization terms of the sparse coding framework to characterize the statistics of realistic noise and image priors. TWSC can be reformulated as a linear equality-constrained problem and can be solved by the alternating direction method of multipliers. The existence and uniqueness of the solution and convergence of the proposed algorithm are analyzed. Extensive experiments demonstrate that the proposed TWSC scheme outperforms state-of-the-art denoising methods on removing realistic noise.

Finally, to benchmark the real-world image denoising problem, and to complement the previous datasets, we construct a new dataset which contains more comprehensive scene contents with more camera brands and camera settings. Extensive comparison experiments are performed on existing and our new benchmark datasets. The results show that our new dataset is more challenging than previous ones, and real-world image denoising is still a challenging task which needs broader and deeper study.

In summary, in this thesis we investigate in-depth the learning of NSS priors for image denoising, develop several new and effective denoising models, and present a new dataset of real-world noisy images. The research outputs of this these not only enrich the understanding of NSS based statistical image modeling, but also demonstrate state-of-the-art performance in image denoising, especially real-world image denoising.

Keywords: Real-world image denoising, Nonlocal self-similarity, Sparse models, Low-rank models.