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TOKYO INSTITUTE OF TECHNOLOGY

SIGNAL DEPENDENT NOISE ESTIMATION AND REMOVAL FROM A SINGLE IMAGE

A dissertation submitted in partial satisfaction of the requirements for the degree of

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Chapter 1

Outline

Existing image denoising algorithms usually assume a signal independent additive white Gaussian noise (AWGN) with known noise level. Such non-blind denoising approaches cannot automatically and effectively remove signal dependent noise produced by real imaging systems. To solve this problem, in this thesis we propose a complete blind denoising framework which aims to automatic estimate and remove the signal dependent noise from a single image.

We start from proposing an accurate noise level estimation algorithm for the AWGN based on Principal Component Analysis (PCA) and the low-rank patches of the image. Next, we extend this approach to estimate the noise level function (NLF) of signal dependent noise. For denoising, we study the generalized signal dependent (GSD) noise model and propose a denoising algorithm based on variance stabilization transform (VST). We derive the variance stabilization transform and its unbiased inverse transform for GSD noise. Then the denoising can be performed with any high performance Gaussian noise removal algorithm in the transform domain. Finally, combining these two modules, we develop a full blind denoising framework for signal dependent noise from a single image. Extensive experiments are conducted to evaluate each module of the proposed framework, which are shown to outperform state-of-the-art noise estimation and denoising algorithms

Chapter 1, Introduction. In this chapter we introduce the noise models and briefly review the recent noise estimation and image denoising algorithms. In current literature, non-blind denoising algorithm for Gaussian noise is intensively studied, however, they are not automatic and practical. This motivates us to develop a complete blind denoising framework for practical use. We also introduce the performance evaluation method for denoising and state-of-the-art performance as well as the contribution of this dissertation.

Chapter 2, Noise Estimation for Signal Independent Gaussian Noise. Noise level is an important parameter to many image processing applications. For example, the performance of an image denoising algorithm can be much degraded due to the poor noise level estimation. Most existing denoising algorithms simply assume the noise level is known that largely prevents them from practical use. Moreover, even with the given true noise level, these denoising algorithms still cannot achieve the best performance, especially for scenes with rich texture. In this chapter, we propose a patch-based noise level estimation algorithm and suggest that the noise level parameter should be tuned according to the scene complexity. Our approach includes the process of selecting low-rank patches without high frequency components from a single noisy image. The selection is based on the gradients of the patches and their statistics. Then, the noise level is estimated from the selected patches using principal component analysis. Because the true noise level does not always provide the best performance for nonblind denoising algorithms, we further tune the noise level parameter for nonblind denoising. Experiments demonstrate that both the accuracy and stability are superior to the state of the art noise level estimation algorithm for various scenes and noise levels.

Chapter 3, Noise Estimation for Signal Dependent Noise. The additive white Gaussian noise (AWGN) is widely assumed in many image processing algorithms. However, in the real world, the noise from actual cameras is better modeled as signal dependent noise (SDN). In this chapter, we focus on the SDN model and propose an algorithm to automatically estimate its parameters from a single noisy image. The proposed algorithm identifies the noise level function of signal dependent noise assuming the generalized signal dependent noise model and is also applicable to the Poisson-Gaussian noise model. The accuracy is achieved by improved estimation of local mean and local noise variance from the selected low-rank patches. We evaluate the proposed algorithm with both synthetic and real noisy images. Experiments demonstrate that the proposed estimation algorithm outperforms the state of the art methods.

Chapter 4, Noise Removal for Signal Dependent Noise. Generalized Signal Dependent (GSD) noise model is a fully parametric model which takes into account different noise generation processes, like Poisson, speckle and film-grain noise. In this chapter, we present a Variance Stabilization Transform (VST) based noise removal algorithm for GSD noise model. Specifically, we propose the forward variance stabilization transform and its exact unbiased inverse for the GSD noise model. Then combining with a state-of-the-art Gaussian noise removal algorithm, the proposed algorithm is not only competitive with that of a state-of-the-art algorithm designed for the removal of Poisson-Gaussian noise but also maintains high performance for various other types of noise. Further, we conduct experiments to show that incorporating with the noise estimation algorithm, and the denoising performance has almost no decline. Thus a practical full blind, high quality denoising algorithm for signal dependent noise is achieved.

Chapter 5, Conclusions and Future Works. In this chapter, we conclude the dissertation and briefly mention the possible future works which includes: noise estimation and denoising performance improvements for rich textured images, extension of current algorithm to color image denoising, video denoising and so on.