

The Hong Kong Polytechnic University

Department of Computing

**External and Internal Nonlocal
Self-Similarity based Models
for Image Denoising**

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**A thesis
submitted in partial fulfilment of the requirements
for the degree of**

Doctor of Philosophy

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CERTIFICATE OF ORIGINALITY

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Abstract

The nonlocal self-similarity (NSS) prior of natural images has been extensively studied in many image restoration methods. In this thesis, we exploit the NSS property of external natural images, external guided internal NSS property, and internal NSS property for image denoising tasks.

Acknowledgement

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Introduction

” *"Mens cujusque is est Quisque" – "Mind
Makes the Man"*

— Samuel Pepys

Nowadays, cameras are becoming more and more widely used in many aspects of human lives such as taking pictures, medical analysis, security monitoring and control, etc. The camera imaging pipelines are of particular importance since it is the key step of transforming the real scenes into the pictures or videos. However, during the imaging process, the noise is unavoidable to be generated due to many reasons.

1.1 The Camera Imaging Pipeline

The cameras capture the images and store as raw image formats. During the camera imaging pipeline, the photons are transformed into electronics by the photodiode in the camera sensor. The original sensor array (also called color filter array, or CFA) contains red, green, and blue channels, and these incomplete channels are transformed into the final RGB files via the raw converter. The camera imaging pipeline includes multiple stages such as reading raw image, black light subtraction, lens correction, demosaicing, noise reduction, white balancing, gamma curve, final color space conversion, etc [brownecv2016]. Basically, a camera imaging pipeline includes demosaicing, white balancing and color space transform, gamut mapping, tone mapping, and JPEG compression [crosschannel]. However, different cameras have varying structures and camera parameters, and hence resulting different imaging effects. Recently, there also exists learning based imaging pipelines which directly learn the natural image priors from the RGB and raw images pairs.

1.2 The Image Noise

During the imaging pipeline, the noise will be generated. The key reason of noise generation is unstable measurement from the discrete nature of light and the thermal agitation.

The major sources of noise generated during the imaging pipeline are the random noise, the spatial non-uniformity, and quantization noise. The random noise includes photon shot noise, dark current, and readout noise. The spatial non-uniformity noise includes the fixed pattern noise (PRNU, DCNU), CCD/CMOS specific noise.

A simplified model including various noise sources (for each pixel):

$$P = f((g_{cv}(C + D) + N_{reset})g_{out} + N_{out}) + Q. \quad (1.1)$$

Now the above equation is explained in details. P is the raw pixel value, C is the number of absorbed electrons (charges) transformed from the photons via the photon-diodes in the camera sensor, D is the number of absorbed electrons generated by dark current, g_{cv} is the equivalent capacitance (EC) of the photo-diode, N_{reset} is the thermal noise generated by the readout circuitry (or reset noise related to reset voltage), g_{out} is the gain factor during voltage to pixel value conversion (readout), N_{out} is the readout noise, f is the camera response function, usually a linear function before attaining a saturation threshold, Q is the quantization error happened during rounding to interger values. The quantization noise is normally negligible compared to the readout noise.

1.3 The Proposed Methods

1.4 Thesis Structure

Chapter ??

Chapter ??

Chapter 5

Chapter 7

Chapter 8

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2.1 Synthetic Grayscale Image Denoising

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2.2 Realistic Color Image Denoising

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External Non-local Self-Similarity

Prior for Additive White Gaussian Noise

” *Innovation distinguishes between a leader and a follower.*

— Steve Jobs
(CEO Apple Inc.)

3.1 Introduction



Fig. 3.1: Figure example: (a) example part one, (c) example part two; (c) example part three

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Fig. 3.2: Another Figure example: (a) example part one, (c) example part two; (c) example part three

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3.2 System Design

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3.3 Demo System

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3.4 Calibration

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3.5 Conclusion

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External Prior Guided Internal Prior Learning for Real Noisy Image Denoising

“Innovation distinguishes between a leader and a follower.

— Steve Jobs
(CEO Apple Inc.)

4.1 Learning External Nonlocal Self-Similarity Priors



Fig. 4.1: Figure example: (a) example part one, (c) example part two; (c) example part three

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Fig. 4.2: Another Figure example: (a) example part one, (c) example part two; (c) example part three

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Internal Nonlocal Self-Similarity Prior for Real Color Image Denoising: A Low Rank based Method

” *Users do not care about what is inside the box, as long as the box does what they need done.*

— **Jef Raskin**

about Human Computer Interfaces

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5.2 Related Work

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5.3 Method

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5.4 Experimental Results

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5.5 Summary

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Conclusions

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8.1 Section 1

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8.2 Section 2

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8.3 Future Work

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