

DOCTORAL THESIS

Optimization based methods for image segmentation and image tone mapping

Qiao, Motong

Date of Award:
2014

[Link to publication](#)

General rights

Copyright and intellectual property rights for the publications made accessible in HKBU Scholars are retained by the authors and/or other copyright owners. In addition to the restrictions prescribed by the Copyright Ordinance of Hong Kong, all users and readers must also observe the following terms of use:

- Users may download and print one copy of any publication from HKBU Scholars for the purpose of private study or research
- Users cannot further distribute the material or use it for any profit-making activity or commercial gain
- To share publications in HKBU Scholars with others, users are welcome to freely distribute the permanent URL assigned to the publication

Abstract

Optimization methods have been widely utilized in the field of imaging science, such as image denoising, image segmentation, image contrast adjustment, high dynamic range imaging, etc. In recent decades, it is becoming more and more popular to reformulate an image processing problem into an energy minimization problem, then solve for the minimizer by some optimization based methods. In this thesis, we concern solving three popular issues in image processing and computational photography by optimization based methods, which are image segmentation, bit-depth expansion, and high dynamic range image tone mapping problems.

The contribution of this thesis can be illustrated in three parts separately according to different topics. For the image segmentation problem, we present a multi-phase image segmentation model based on the histogram of the Gabor feature space, which consists of responses from a set of Gabor filters with various orientations, scales and frequencies. Our model replaces the error function term in the original fuzzy region competition model with squared 2-Wasserstein distance function, which is a metric to measure the distance of two histogram. The energy functional is minimized by alternating direction method of multiplier, and the existence of the closed-form solutions is guaranteed when the exponent of the fuzzy membership term being 1 or 2. The experimental results show the advantage of our proposed method compared to other recent methods.

As for the bit-depth expansion problem, we develop a variational approach containing an energy functional to determine a local mapping function for bit-depth expansion via a smoothing technique, such that each pixel can be adjusted locally to a high bit-depth value. In order to enhance the contrast of the low bit-depth images,

we make use of the histogram equalization technique for such local mapping function. Both bit-depth expansion and histogram equalization terms can be combined together into the resulting objective function. In order to minimize the differences among the local mapping functions at the nearby pixel locations, the spatial regularization of the mapping is incorporated in the objective function.

Regarding the tone mapping problem for high dynamic range images, we propose a computational tone mapping operator which makes use of a localized gamma correction. Our tone mapping operator combines the two subproblems in the tone mapping problem, i.e. luminance compression and color rendering, into one general framework. The bright regions and dark regions can be distinguished and treated differently. In our method, we propose two adjustment rules according to the perceptual preference of human visual system towards contrast and colors respectively. The resulting tone mapped images have a natural looking and the highest score in our observer subjective test.

Based on the motivation of our computational tone mapping operator, we propose a variational method for image tone mapping problem. The core idea is to minimize the difference of the local contrast between the tone mapped image and the high dynamic range image under some constraints. The energy functional contains a local contrast fidelity term and a L-2 total variation regularization term. Local gamma correction is also applied as our previous computational model and the unknown variables are the non-uniform gamma values. The non-uniform gamma values for each pixel can be obtained by minimizing the fidelity term, while the smoothing term ensures the gamma values for nearby pixels not varying too much from each other. The results by both our computational and variational tone mapping operators show advantage in preserving the detailed image contents in the bright and dark regions.

Keywords: optimization, alternating direction method of multipliers, variational model, image segmentation, Mumford-Shah model, Gabor filter, contrast adjustment, histogram equalization, bit-depth expansion, dynamic range, HDR imaging, tone mapping operators, gamma correction, color rendering.

Acknowledgements

It is a great opportunity to express my deep thanks to all the people who have helped me during my Ph.D study and made this thesis possible.

First and foremost, I would like to express my deep gratitude and appreciation to my principle supervisor Prof. Michael K. Ng for his guidance, encouragement and patience throughout the past three years. He offered me the chance of pursuing my Ph.D study at the end of my M.Sc academic year, and introduced me to the research field of image processing. He has generously shared his knowledge, motivated me to work harder and show me the way of independent thinking all the time. Besides his broad knowledge and innovative ideas in the field of academic research, what impresses me most is his dedicated attitude and great passion towards every trivial work. It is my great honor to be his student. I would also like to thank my co-supervisor Dr. Tiejong Zeng, for his kindly help and career suggestions.

I would like to thank Prof. Wen Li, Dr. Aijun Zhang, Dr. Xiaoming Yuan, Dr. Chipan Tam, Dr. Fang Li, Dr. Fan Wang and Dr. Xile Zhao, for their advices and fruitful discussion. They have brought me a broader view of different academic fields.

I am grateful to all faculties and postgraduate students in our department for their accompany and help. In particularly, I should mention Ms. Yangliu, Ms. Wei Zhang, Ms. Liyuan Chen, Ms. Xinxin Li, Mr. Chenyang Shen, Mr. Xiaomeng Wu, Mr. Chuan Chen, Mr. Jiang Yang, Mr. Hongwei Li, Mr. Xuehu Zhu, Mr. Wenyi Tian. Besides I would like to express my great appreciation to all the staffs in our department, especially Ms. Claudia Chui, Ms. Natalie Law, Ms. Tammy Lam and Mr. Cheong-Wing Yeung. Without their prudential work, my Ph.D life would not be so enjoyable.

Finally I would like to thank my family members who gave me unreserved love and have always supported my decisions.

Table of Contents

Declaration	ii
Abstract	iii
Acknowledgements	v
Table of Contents	vii
List of Tables	x
List of Figures	xi
Chapter 1 Introduction	1
1.1 Image Segmentation	1
1.2 Image Bit-Depth Expansion	1
1.3 High Dynamic Range Image Tone Mapping	2
1.4 Thesis Outline	4
Chapter 2 Multi-phase Texture Segmentation Based on Gabor Features Histograms	6
2.1 Introduction	6
2.2 Background Review	7
2.2.1 Previous Methods	7
2.2.2 Related Knowledge	9
2.3 Proposed Method	10
2.3.1 Related Work	10

2.3.2	Proposed Model	12
2.3.3	Numerical Analysis	13
2.3.4	Proposed Algorithm	16
2.4	Experimental Results	19
2.4.1	Gabor filter selection	19
2.4.2	Numerical Examples	21
2.5	Conclusions and Discussions	23

Chapter 3 Variational Method for Expanding the Bit-Depth of Low Contrast Image 27

3.1	Introduction	27
3.2	Previous Methods	28
3.2.1	Zero Padding	28
3.2.2	Bit Replication	29
3.2.3	Multiplication by an Ideal Gain	29
3.2.4	Gamma Expansion	29
3.2.5	Other Methods	29
3.3	Proposed Method	30
3.3.1	Related Work	30
3.3.2	Proposed Model	31
3.3.3	Algorithm	33
3.4	Nummerical Results	34
3.5	Conclusions and Discussions	36

Chapter 4 Computational Tone Mapping for High Dynamic Range Images 41

4.1	Introduction	41
4.2	Previous Methods	42
4.2.1	Global Tone Mapping Operators	42
4.2.2	Local Tone Mapping Operators	43
4.3	Proposed Method	45

4.3.1	Related Work	45
4.3.2	Proposed Model	46
4.3.3	Contrast Rule	47
4.3.4	Saturation Rule	50
4.4	Experimental Results	53
4.5	Conclusions and Discussions	55
Chapter 5 Variational Tone Mapping for High Dynamic Range Images		63
5.1	Introduction	63
5.2	Previous Methods	63
5.2.1	Histogram-based Variational Tone Mapping	64
5.2.2	Structure-based Variational Tone Mapping	64
5.3	Proposed Method	65
5.3.1	Proposed Model	65
5.3.2	Proposed Algorithm	66
5.4	Experimental Results	67
5.5	Conclusions and Discussions	69
Chapter 6 Summary		79
Bibliography		81
Curriculum Vitae		90