DOCTORAL THESIS

Optimization based methods for image segmentation and image tone mapping

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Abstract

Optimization methods have been widely utilized in the field of imaging science, such as image denoising, image segmentation, image contrast adjustment, high dynamic rang 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.

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