INTRODUCTION

We address the intrinsic image decomposition problem for separating an image into its intrinsic images, i.e., a reflectance layer and a shading layer. Although this problem has been studied for decades, it remains a significant challenge, particularly for real-world images. In this paper, we present a novel method for estimating high-quality intrinsic images for real-world images. Our method is built upon two observations on real-world images: (i) reflectance is generally sparse and there are limited number of reflectance values in an image; (ii) shading usually has locally smooth transition. Based on the two observations, we formulate the decomposition problem into an optimization framework, where we encourage the reflectance sparseness by globally confining the number of reflectance discontinuities among neighboring pixels using an $L_0$ norm, and utilize a total variation for maintaining locally smooth shading. We employ two benchmark datasets and perform various experiments to evaluate our method. Experimental results show that our method outperforms state-of-the-art methods, both qualitatively and quantitatively.

PROPOSED METHOD

We formulate the intrinsic image decomposition problem as the minimization of the following objective function:

$$\arg\min_{R, S} ||R - S||^2_2 + \lambda_1 ||\nabla S||^2_2 + \lambda_2 ||S - \hat{S}||^2_2 + \lambda_3 ||f_s|| + \lambda_4 ||f_r||, s.t. I = S + R,$$  

(1)

where $f_s$, $f_r$, and $f_e$ are different energy terms. $\lambda_1$, $\lambda_2$, and $\lambda_3$ are all positive balancing weights.

Reflectance sparsity term. Our one key observation is that the reflectance of the real-world images is more sparse, i.e., piecewise constant. Based on this observation, we encourage the reflectance sparseness by globally confining the number of reflectance discontinuities using an $L_0$ norm, which is defined as

$$f_s = ||\nabla R||_0,$$  

(3)

where $\nabla$ is the gradient operator. Intuitively, this $L_0$ norm term forces small reflectance discontinuities or noises to be zeros, while preserving the prominent structure of reflectance.

Shading smoothness term. Our second observation is that shading tends to vary smoothly across smooth surfaces. This observation on shading helps to determine the reflectance for textured object, since it is common knowledge that textures in real-world images are more likely to be incurred by reflectance instead of shading variations. Hence, we include a total variation based shading smoothness term:

$$f_r = ||\nabla S||_2^2,$$  

(4)

Absolute scale term. Besides the shading smoothness term, we also impose a absolute scale constraint for shading, which is expressed as

$$f_e = ||S - \hat{S}||^2_2,$$  

(5)

where $\hat{S}$ is a constant positive. In our experiments, we empirically set $\hat{S} = 0.5$.

MODEL SOLVER

The objective function in Eqn. (1) is non-convex due to the $L_0$ norm regularization. We adopt the alternating direction method of multipliers (ADMM) technique to solve the optimization problem model by dividing the intractable problem into several tractable subproblems.

To apply ADMM, we introduce an auxiliary variable $G = \nabla R$ and an error variable $X$, and rewrite the objective function in Eqn. (1) as the following equivalent form:

$$\arg\min_R ||R - S||^2_2 + \lambda_1 ||\nabla S||^2_2 + \lambda_2 ||S - \hat{S}||^2_2 + \lambda_3 ||f_s|| + \lambda_4 ||f_r||, s.t. ||G||_0 + \mu ||\nabla R - G + X||_2^2 \leq S,$$  

(6)

where $\gamma > 0$ is the penalty parameter. The following figure shows how the results updated with the iterations increased, and the convergence curves for reflectance and shading.

EXPERIMENTAL RESULTS

Visual comparison:

Ablation study for $f_s$: Comparison between our proposed $L_0$ norm with $L_2$ and $L_1$ norm in encouraging reflectance sparsity. (b)-(c) are the estimated reflectance layers derived from different sparsity pursuit norms ($L_1$ and $L_0$).

Ablation study for $f_r$: Comparison of shading produced by our method without and with the shading smoothness term. We can see that, without the term, there are erroneous texture residuals in the shading layer, while adding the term removes the issue.

APPLICATION TO LOW-LIGHT IMAGE ENHANCEMENT

Our method is applicable to low-light image enhancement with the similar operation as $[1, 5]$. We can see that, the LIME [1] overexposes the leaves and the sky, while our method produces more-appealing result with moderate brightness, clear details, distinct contrasts and vivid color.

Limitations: The limitation of our method is that it may wrongly assign hard shadows that violate the Lambertian assumption to the reflectance layer. We can see that, the cast shadow led by shading discontinuities also exists in the reflectance layer.

REFERENCES