Single Image Reflection Suppression

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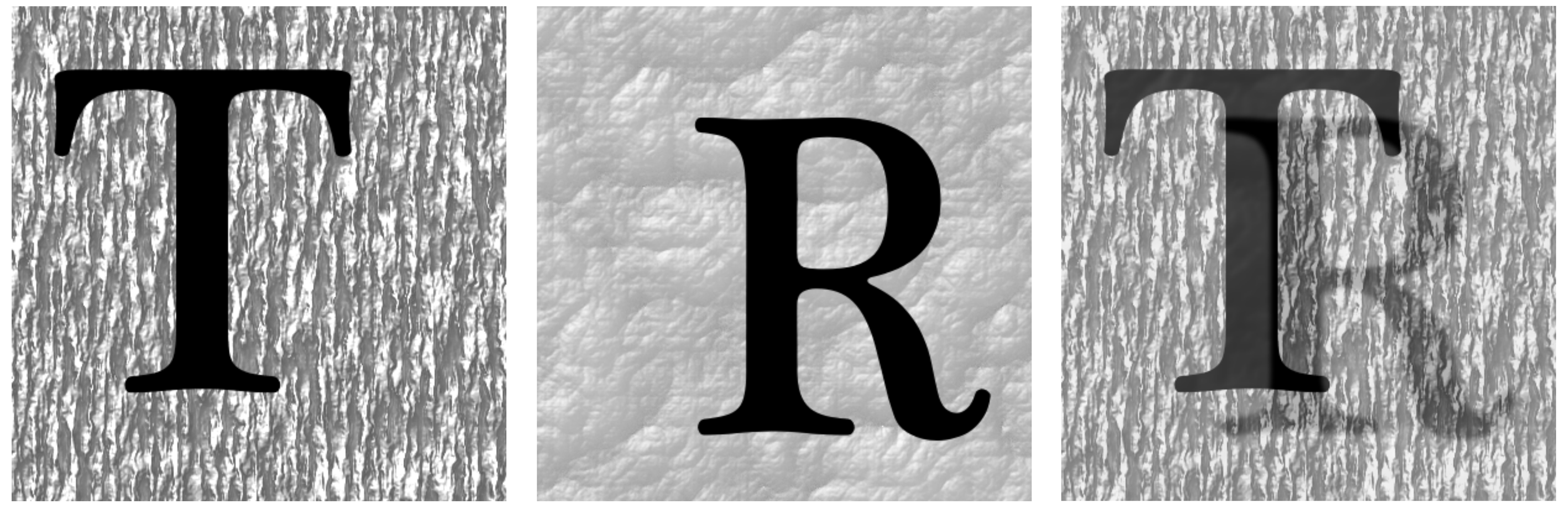
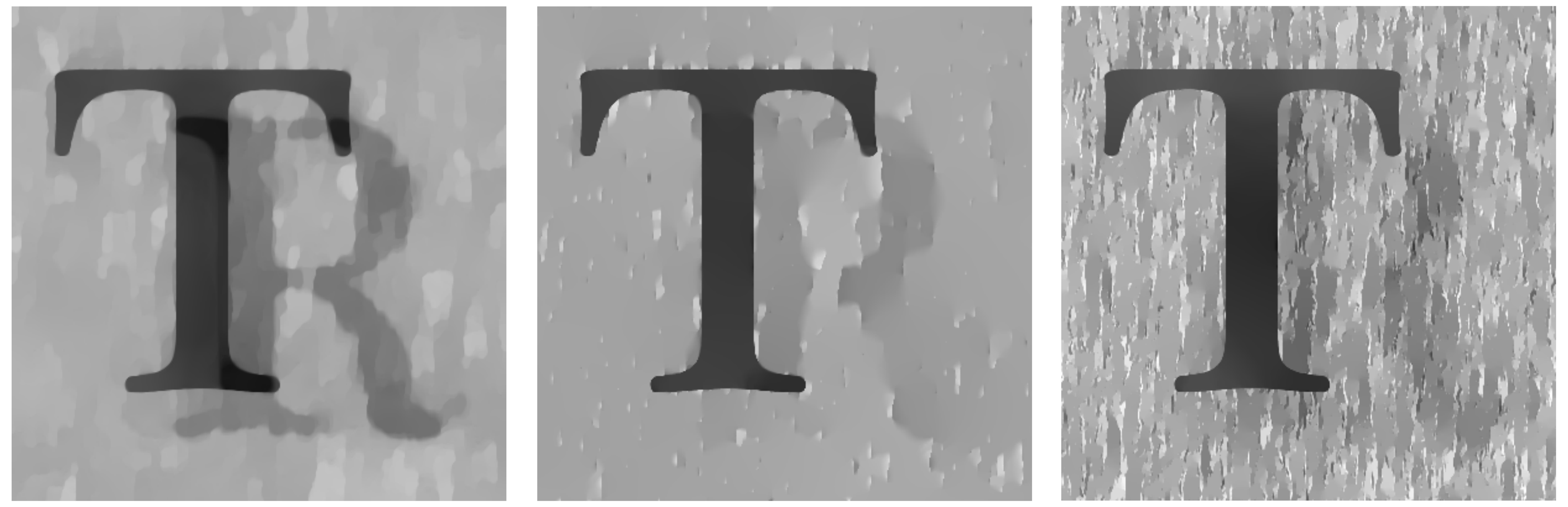
Input image — Our reflection removal result

Introduction

Automatically removing reflections from a single image is a highly ill-posed problem. We propose an efficient solution that performs better than the state-of-the-art. We propose to suppress reflections using an optimization objective based on the ℓ_0 gradient prior. We use a modified data fidelity term based on the Laplacian operator in order to maintain structures of high detail. Our algorithm provides state-of-the-art results in reflection removal in several realistic scenarios.



a) Transmission — b) Reflection — c) Synthetic Blend



d) $\ell_1,\ \lambda = 0.5$ — e) [Xu et al., 2011] $\lambda = 0.05$ — f) Ours $\lambda = 0.05$

Comparison of different smoothing techniques on a 2-d toy example. The transmission a) and reflection b) images are combined to obtain the synthetic blend c). The goal is to recover the transmission image a) from the synthetic blend c). In the second row, we show image smoothing results d) of the standard ℓ_1 prior, e) the ℓ_0 approach of [Xu et al., 2011] and f) our modified method. Our method f) is better able to maintain important details from the transmission layer c) than the two baseline approaches d) and e).

Our Approach

In the standard reflection model, there is one equation with two unknowns:

$$\mathbf{Y} = \mathbf{T} + \mathbf{R}$$

$\mathbf{Y} \in \mathbb{R}^{n \times m}$: image with reflections

$\mathbf{T} \in \mathbb{R}^{n \times m}$: transmission image

$\mathbf{R} \in \mathbb{R}^{n \times m}$: reflection image

We observe that reflection edges are smaller in magnitude and less in focus than transmission edges. With $\mathbf{k}$ as a blurring kernel and $\mathbf{W}$ as the contribution weights of the transmission, we state:

$$\mathbf{Y} = \mathbf{W} \circ \mathbf{T} + (\mathbf{1} - \mathbf{W}) \circ (\mathbf{k} * \mathbf{R})$$

To better retain continuity of image structures, we use the ℓ_0 prior on the image gradients

$$\mathbf{T}^* = \arg\min_{\mathbf{T}} \|\mathcal{L}(\mathbf{T}) - \mathcal{L}(\mathbf{Y})\|_2^2 + \lambda C(\mathbf{T})$$

$$\mathcal{L}(\mathbf{Y}) = \nabla_{xx}\mathbf{Y} + \nabla_{yy}\mathbf{Y}$$

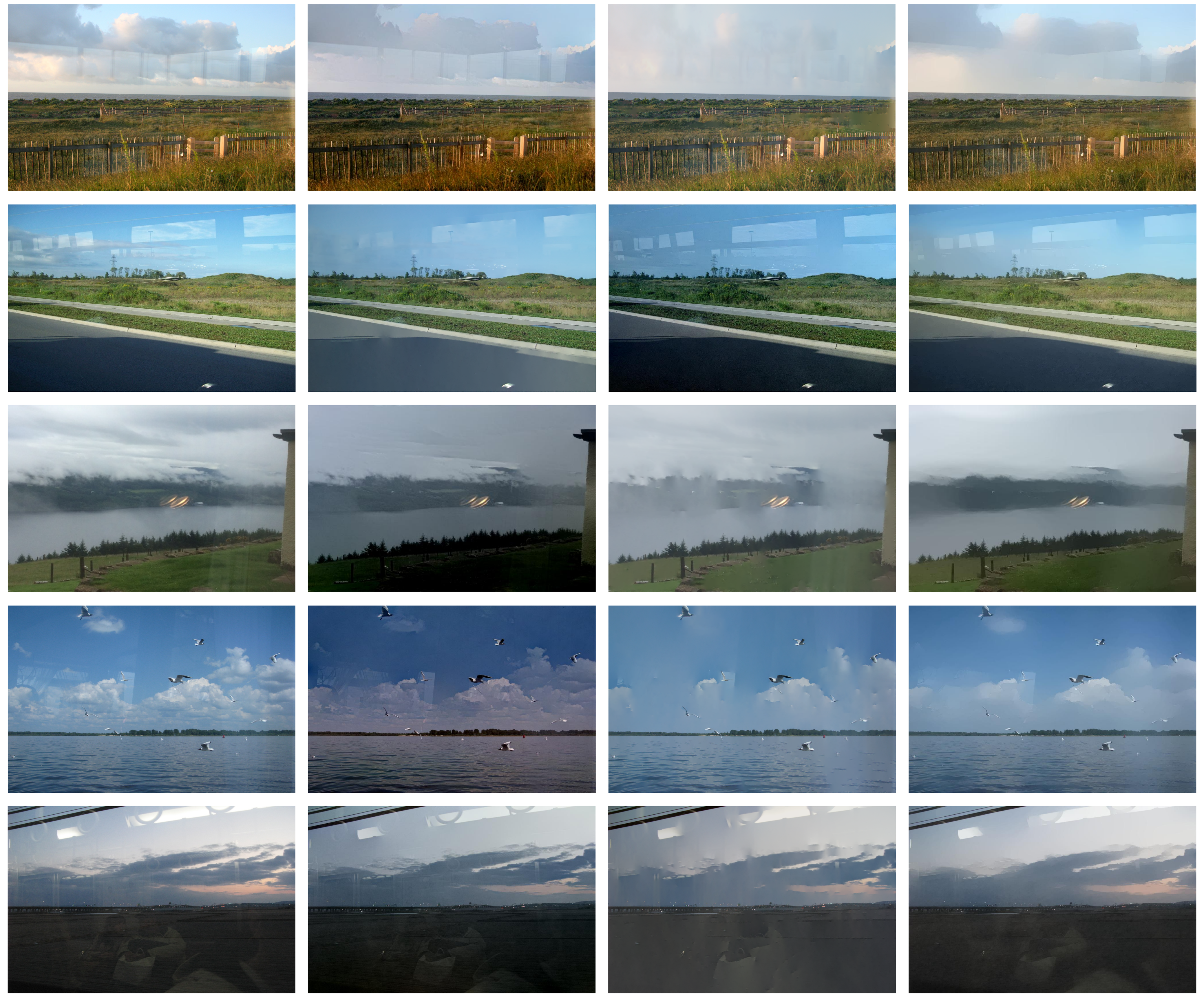
$$C(\mathbf{T}) = \#\{(i,j)\ :\ |\nabla_x T_{i,j}| + |\nabla_y T_{i,j}| \neq 0\}$$

The optimization objective is minimized using the variable splitting approach of [Xu et al., 2011]:

$$\mathbf{T}^*, \mathbf{G}^* = \arg\min_{\mathbf{T},\mathbf{G}} \|\mathcal{L}(\mathbf{T}) - \mathcal{L}(\mathbf{Y})\|_2^2 + \lambda C(\mathbf{G}) + \beta\|\nabla\mathbf{T} - \mathbf{G}\|_2^2$$

Influence of the regularization parameter λ. The larger the parameter λ, the more reflection components are removed. However, some details from the transmission image are also lost.

Evaluation



Input — [Li and Brown, 2014] — [Wan et al., 2016] — Ours

Comparison of reflection removal methods on real-world images. Our method gives superior color reproduction over [Li and Brown, 2014] and reflection suppression over [Wan et al., 2016].

References

Y. Li and M. S. Brown. Single Image Layer Separation Using Relative Smoothness. IEEE CPVR, 2014.
R. Wan, B. Shi, T. A. Hwee and A. C. Kot. Depth of Field Guided Reflection Removal. IEEE ICIP, 2016.
L. Xu, C. Lu, Y. Xu and J. Jia. Image Smoothing via L0 Gradient Minimization. ACM Transactions on Graphics, 2011.