Reflection Removal using Ghosting Cues

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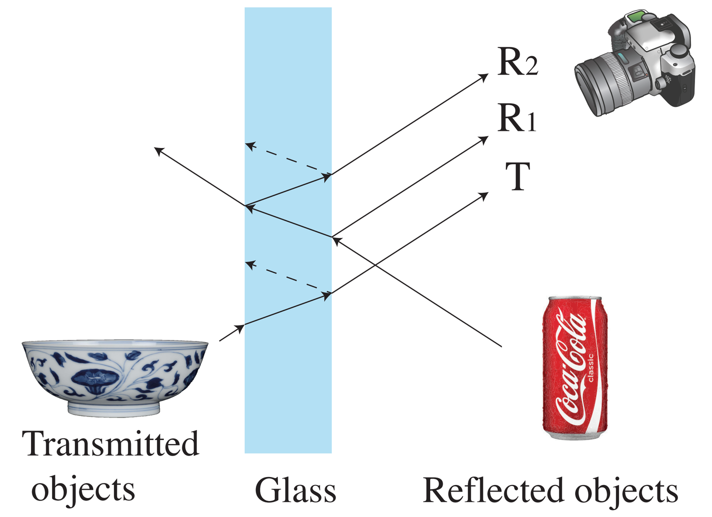
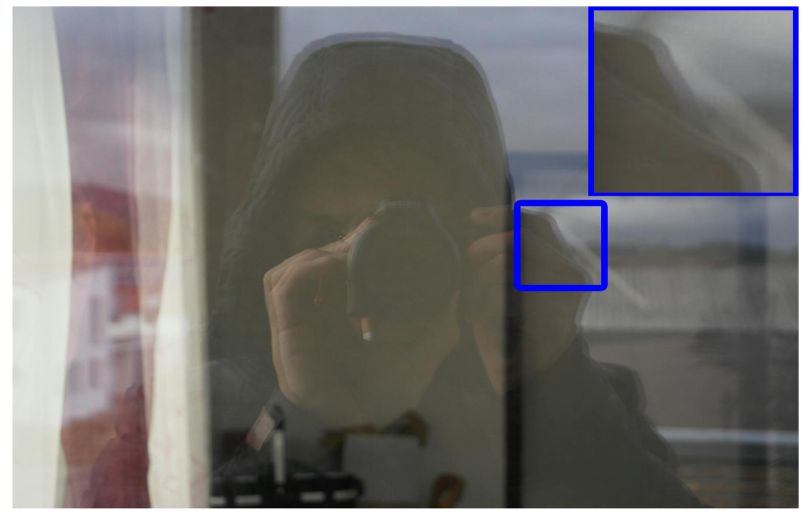
When taking a picture through a window pane, reflections of objects are often captured.



Challenge: in the traditional imaging model $I = T + R$ solving the transmission ***T*** and reflection ***R*** from a single observation ***I*** is ill-posed, since both ***T*** and ***R*** are natural images and appear the same statistical properties.

Our contribution: separate the reflection layer using the double reflection imaging model [1] with patch-based image prior [2].

Key Idea: Break the Symmetry of *T* and *R* using Ghosting

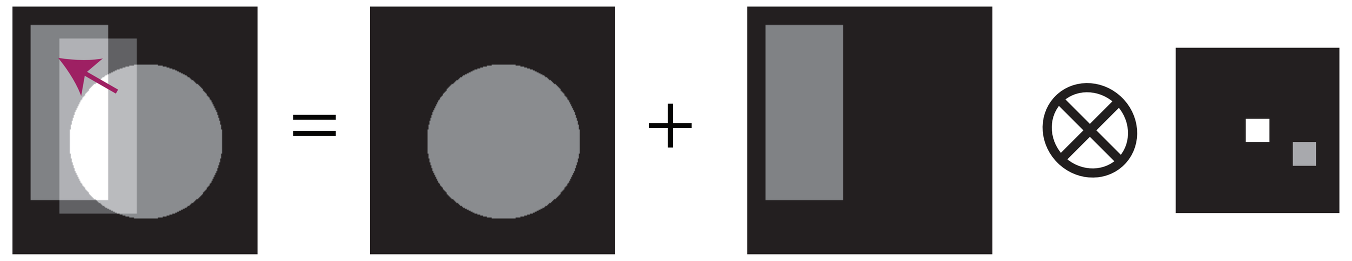


Observation: window reflection often appears multiple times.

Occur on double- and single- paned windows. In single-paned windows, each side creates a reflection. The two reflections are separated by the thickness of the glass.

- Model ghosting phenomenon using a two-pulse kernel ***k***.

$$I = T + R \otimes k$$



- Parameterize ***k*** by the separation of the two reflections ***d*** and an attenuation factor ***α*** depending on the camera view angle. $k(\mathbf{x}) = \delta(\mathbf{x}) + \alpha\delta(\mathbf{x} - \mathbf{d})$

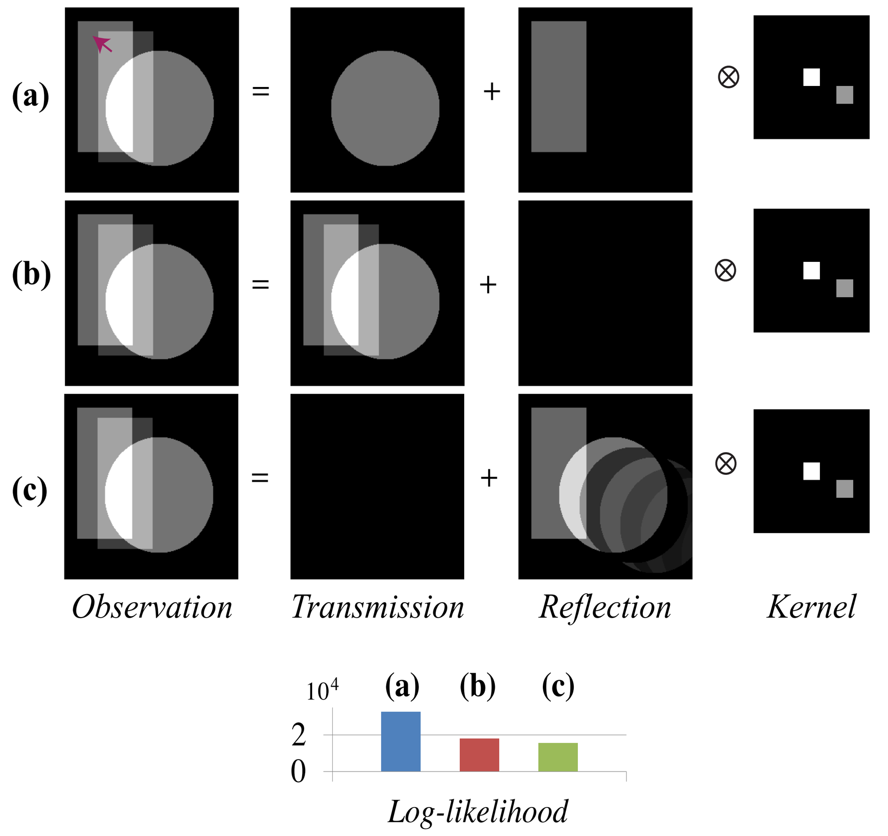
- Estimate ***d*** and ***α*** from the input image ***I*** using auto-correlation function.

Optimization

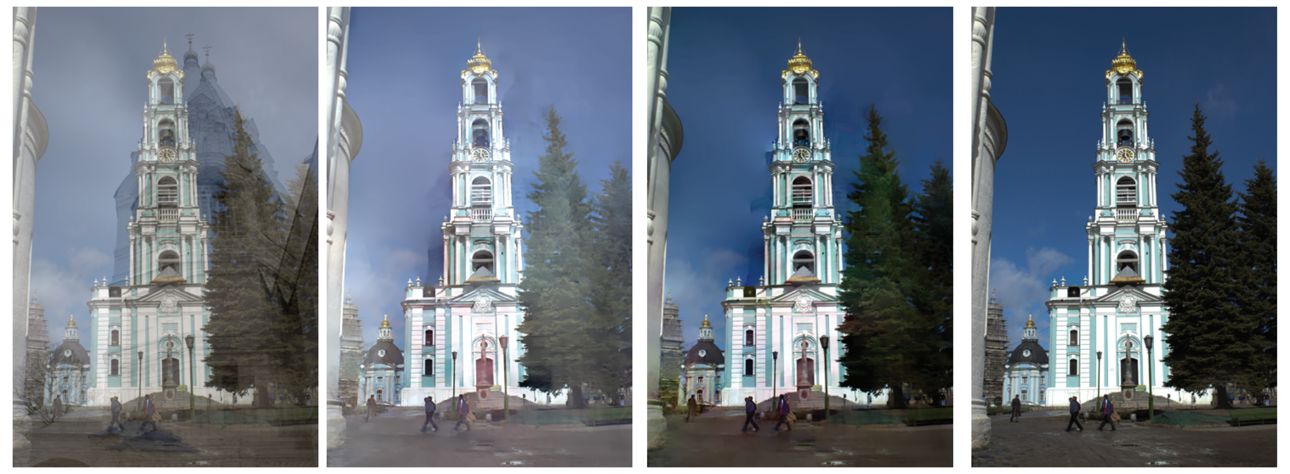
To recover the transmission ***T*** and reflection ***R***, we minimize the following:

$$\underbrace{\frac{1}{\sigma^2}\|I - T - R\otimes k\|_2^2}_{\text{Reconstruction cost}} - \underbrace{\sum_i \log(GMM(P_i T)) - \sum_i \log(GMM(P_i R))}_{\text{Image prior (Gaussian Mixture Model)}} \quad \underbrace{\text{s.t. } 0 \le T,\ R \le 1}_{\text{Non-negativity [3]}}$$

Reconstruction cost | **Image prior (Gaussian Mixture Model)** | **Non-negativity [3]**



We use patch-based Gaussian Mixture Model [2] to regularize image decomposition. Correct decomposition yields higher likelihood.

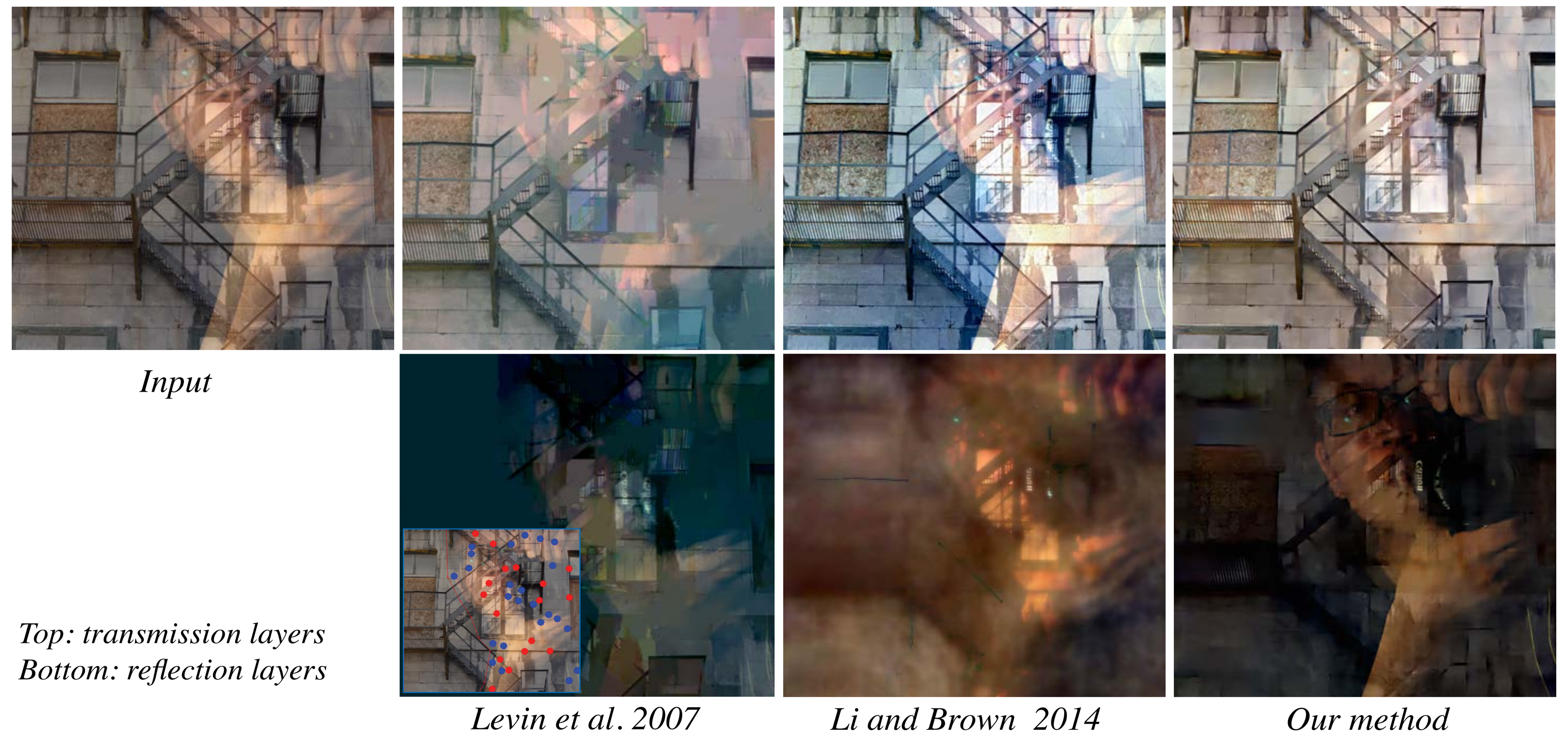


	Synthetic input	GMM-patch prior only	Non-negativity constraints	Ground truth
PSNR	7.04 dB	14.01 dB	26.76 dB	-
SSIM	0.4012	0.5499	0.9083	-

The non-negativity constraint regularizes the low-frequency components in the output, and leads to better colors. The above energy is minimized by bounded L-BFGS optimization.

Input image (***I***) | Transmission layer (***T***) | Reflection layer (***R***)

Comparisons to single image reflection removal



Limitations: we assume sparially-invariant ghostings.
Performance suffers when the transmission layer contains double features.
Low frequencies are still challenging.

References

[1] Y. Diamant and Y. Y. Schechner. Overcoming visual reverberations, CVPR 2008.
[2] D. Zoran and Y. Weiss. From learning models of natural image patches to whole image restoration, ICCV 2011.
[3] R. Szeliski, S. Avidan, and P. Anandan. Layer extraction from multiple images containing reflections and transparency, CVPR 2000.

Acknowledgements

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