Seeing through Obscure Glass

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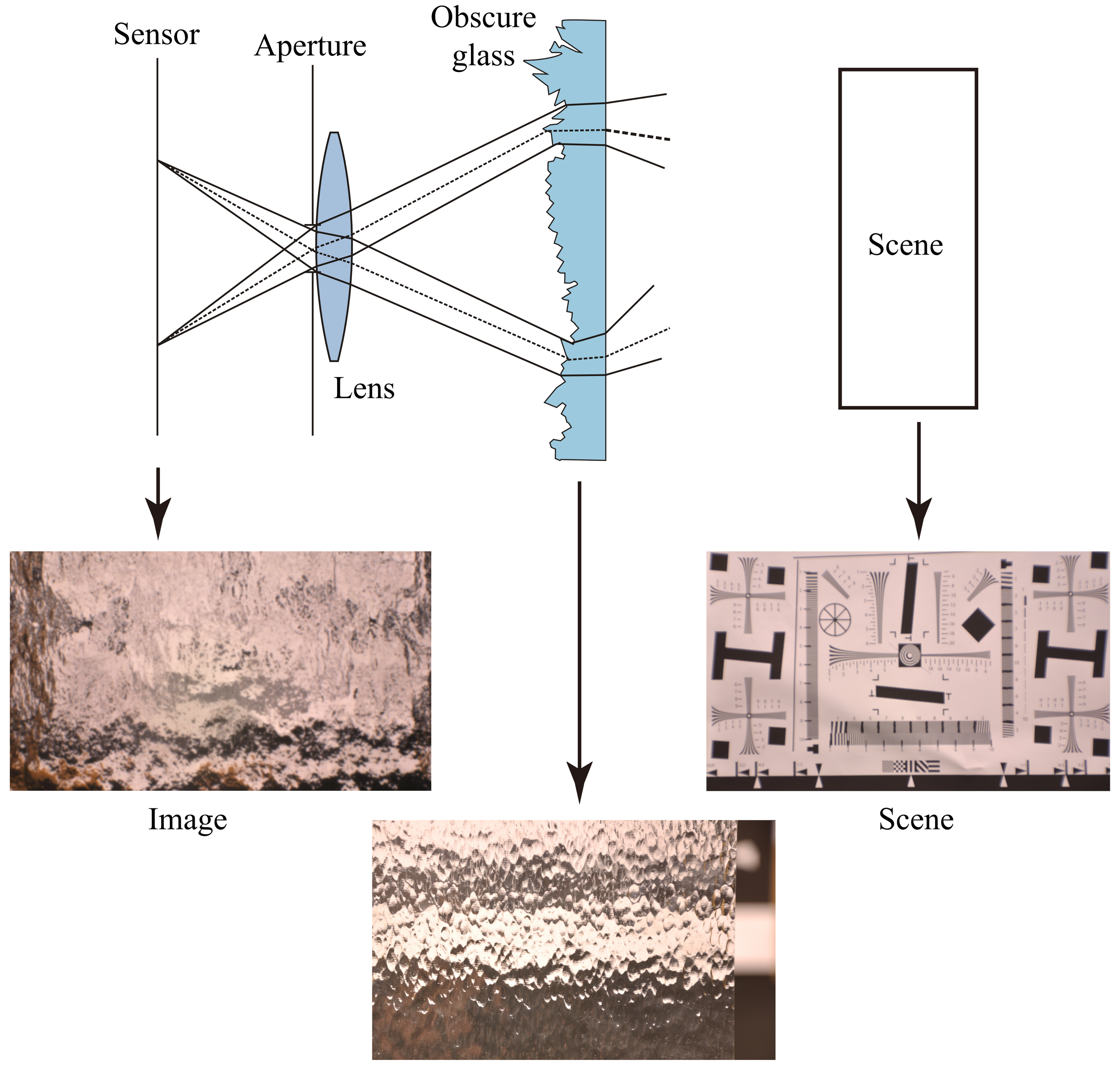
Introduction

Obscure glass is textured glass designed to separate spaces and "obscure" visibility between the spaces. Such glass is used to provide privacy while still allowing light to flow into a space, and is often found in homes and offices. We explore the challenge of "seeing through" obscure glass, using both **digital** and **optical** techniques.

Obscure glass... ...in the home... ...and office

Characteristics of obscure glass

Obscuring effect is primarily due to refraction at the textured surface of the glass.



Obscure glass
(viewed from a distance for visualization here)

Digital approach: calibrate the blur and distortion

The recorded image is a weighted projection of a light field. To simplify, we assume minimal parallax and minimal view-dependent reflection across the rays scattered through aperture-sized regions of the glass.

We can model image formation as spatially varying blur:

I : observed image = $\mathbf{F}$: per pixel kernels · L : latent image

In matrix-vector form, with additive noise N:

$$I = \mathbf{F}L + N$$

$\mathbf{F}$ is the degradation matrix whose rows are per-pixel kernels encoding blur and distortion (displacement).

If we have access to both sides of the glass, we can estimate $\mathbf{F}$ using images of known backgrounds through the glass.

We use fractal (Perlin) color noise backgrounds:

$\mathcal{I} = [\mathbf{I}_1, \mathbf{I}_2, \mathbf{I}_3 \ldots]$ = $\mathbf{F}$ · $\mathcal{L} = [\mathbf{L}_1, \mathbf{L}_2, \mathbf{L}_3 \ldots]$

$\mathbf{F}$ can be large, requiring many images and much computation. E.g., at 400x400 pixels, 50x50 kernels, $\mathbf{F}$ has 400,000,000 vars.

We assume sparse $\mathbf{F}$ (important condition for successful deconvolution) and minimize:

$$E(\mathbf{F}) = \|\mathbf{F}\mathcal{L} - \mathcal{I}\|_2^2 + \gamma\|\mathbf{F}\|_1$$

Combined with a multi-scale optimization in which we lock down zero variables before up-sampling $\mathbf{F}$, we can reduce input images and computation by orders of magnitude.

Results of digital approach

Experimental procedure:

1. Position camera close to glass.
2. Shoot calibration pattern through glass; estimate **F**.
3. Remove, then approximately replace camera.
4. Take multiple shots from nearby viewpoints.
5. Deconvolve **F** with sparse gradient regularization.
6. Keep best image (nearest to original viewpoint).

Obscure glass Input image Output image

Increasing allowed size of kernels

Input image Output (45x45 kernels) Output (95x95 kernels)

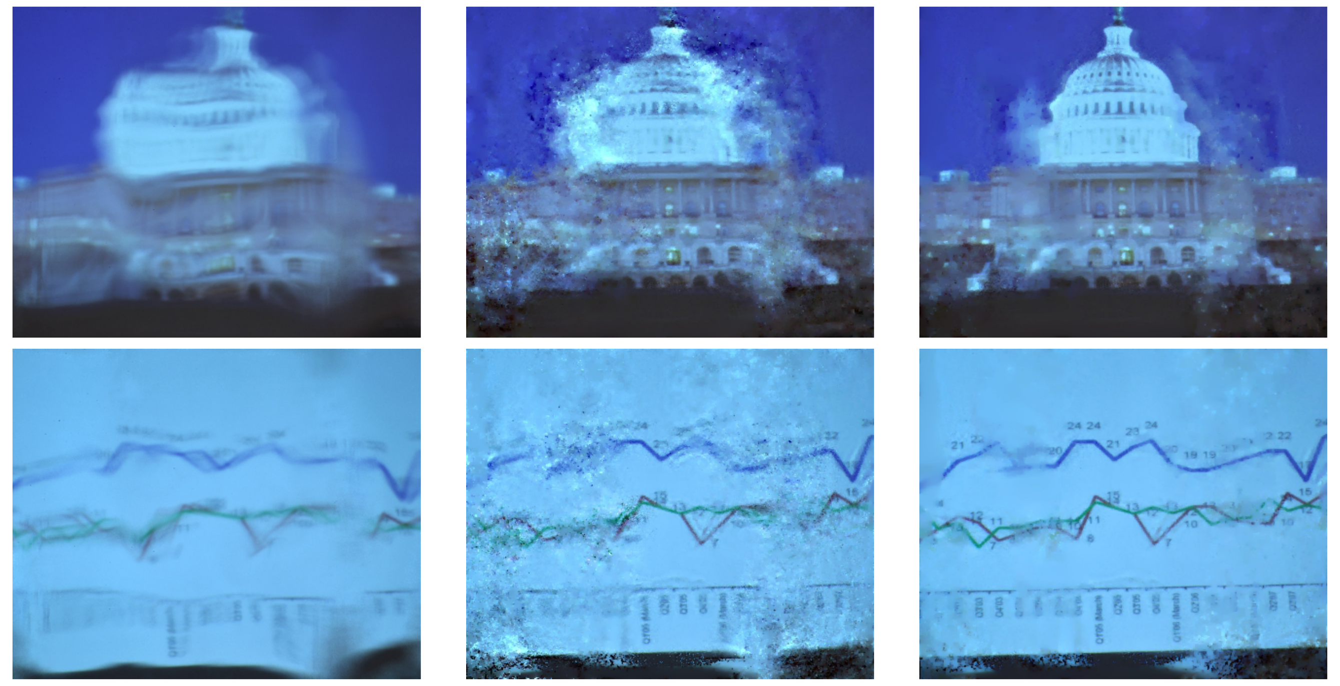
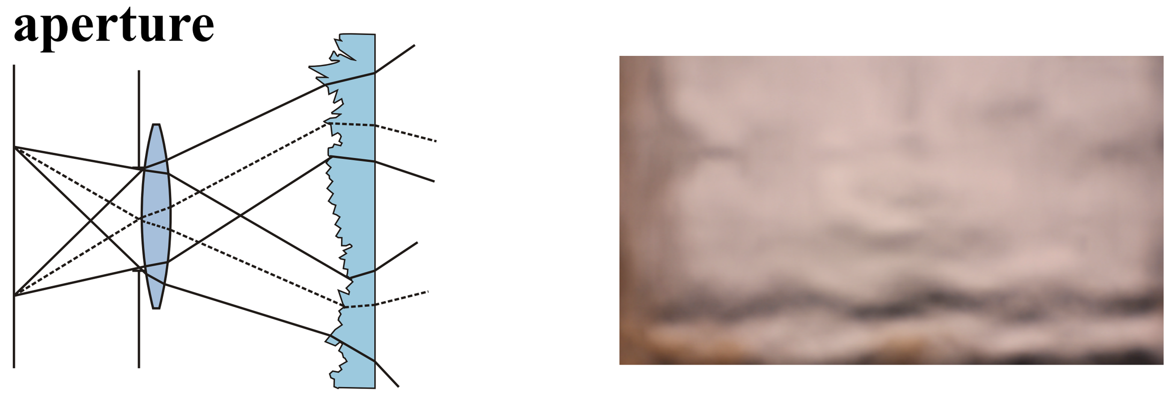


Image sizes: 400x400 Number of calibration images: 120
Kernel estimation*: 40 hrs (45x45 kernels), 200 hrs (95x95)
Deconvolution: ~1 minute
* Kernels estimated independently per pixel, easy to parallelize

Optical approach: cameras and substances

Wide aperture



Result: wide scatter, large distortion

Narrow aperture

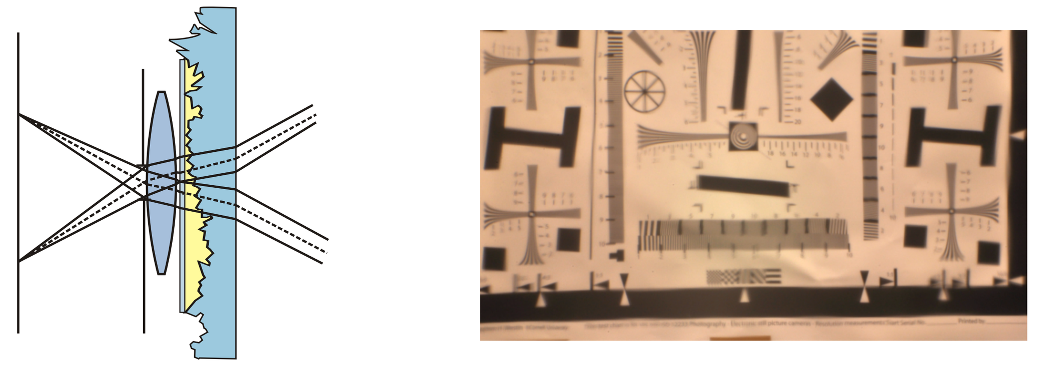
Result: reduced scatter, large distortion

Narrow aperture, close to glass

Result: reduced scatter *and* distortion

Upshot: want a small camera (small aperture and high F-number) which can be close to glass: e.g., iPod Nano.

Applied substance, index of refraction close to glass



Result: when the texture is **on one side and facing outward**, *dramatically* reduced scatter and distortion

Upshot: one-sided, outward-facing obscure glass can be compromised with iPod Nano + thin slide cover + honey.

Limitations

Digital approach requires: sparse-kernel glass,
access to both sides for a period of time, and
ability to re-position camera reasonably well
Applied substance requires access to the textured side(s)
Placing substance and/or camera on glass reveals the observer