Reflection Removal Using Ghosting Cues

Team Psycho07

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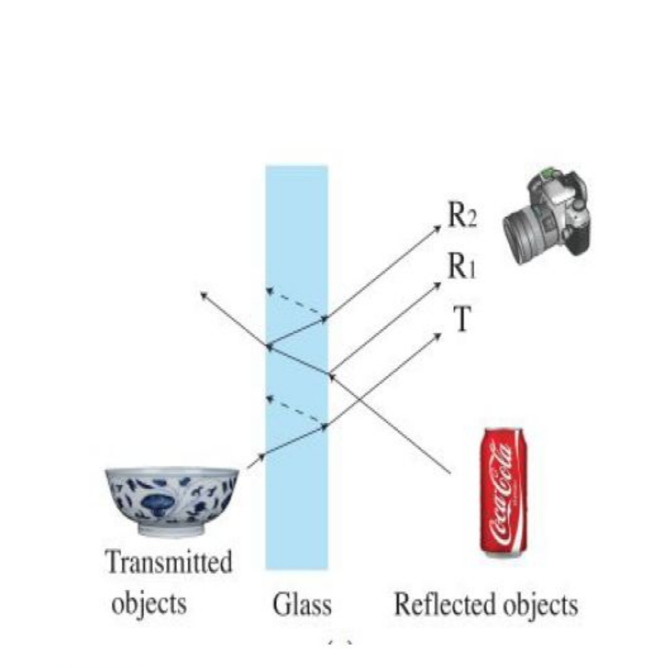
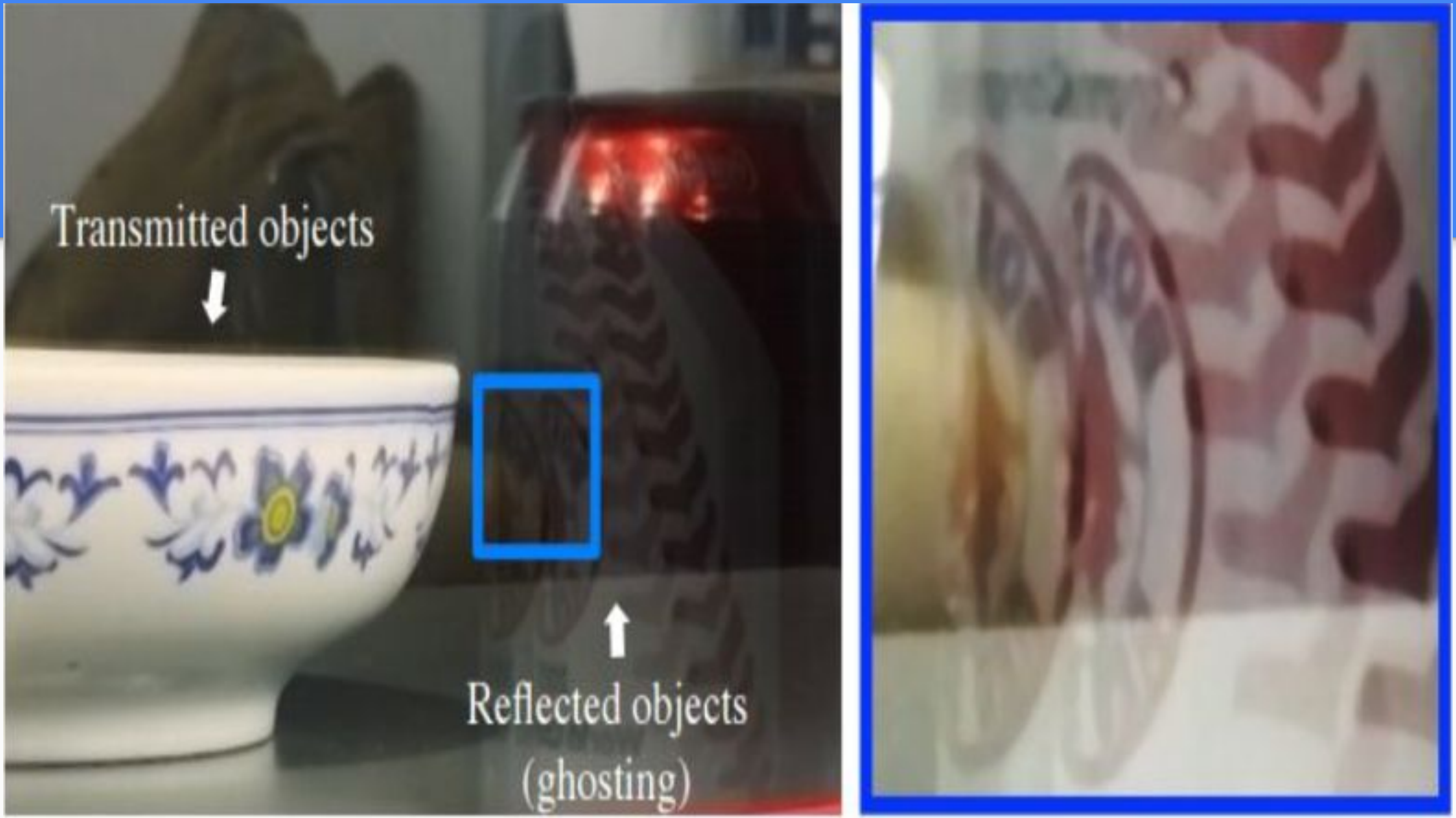
Introduction

When taking a picture through a window pane, reflections of objects are often captured. To minimize reflection artifacts, one may try to change camera position, use polarizers, or put a piece of dark cloth around the camera, but often it is impractical to make any of these adjustments. This raises the need for post-processing to remove reflection artifacts.




Transmitted objects
Reflected objects
(ghosting)

Challenge

Image captured by camera contain both transmitted objects (T) and undesired reflected objects (R). Our aim is to separate T and R.

Traditional Imaging model:

$$I = T + R$$

This model assumes that both T and R play symmetric role when forming output I. As both T and R are natural, separating them is ill-posed since both T and R are natural images and have the same statistical properties.

Key Idea

- Separate the reflection layer using:
    - The double reflection imaging model.
    - With patch-based image prior.
- Break the symmetry of T and R using Ghosting.

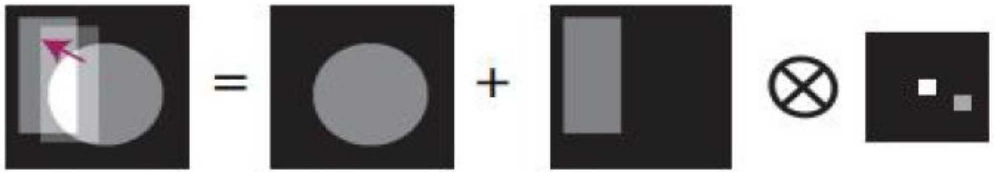
Ghosting

- It can be described as appearance of secondary image on the main display.
- In our problem case , it is caused by multiple reflections.
- Window reflection often appear multiple times causing ghosting for R.
- A common example is a double-pane window, which consists of two thin glass panes separated by some distance. The glass pane at the inner side (closer to the camera) generates the first reflection, and the outer side generates the second, which is a shifted and attenuated version of the first reflection.

Modelling Ghosting

Using a two-pulse kernel k.

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



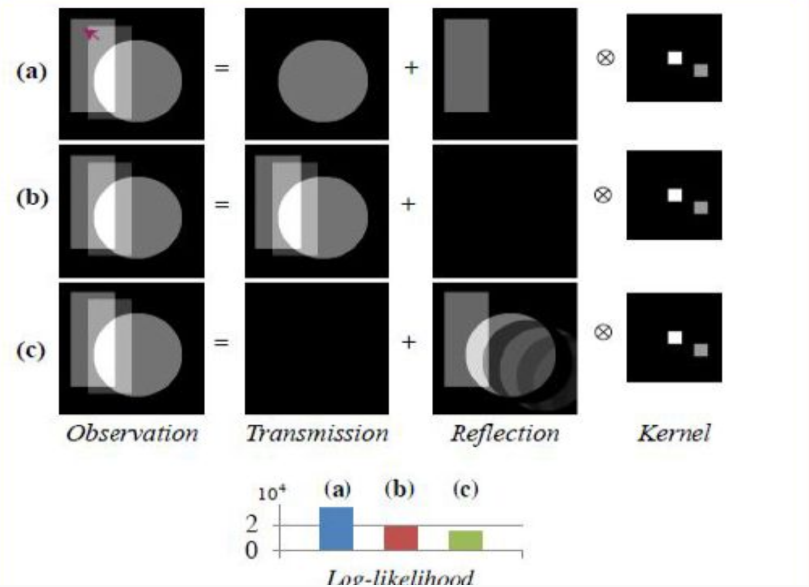
Parameterize k by the separation of the two reflections d and an attenuation factor c depending on the camera view angle.

Assumptions in modelling Ghosting

- We model the kernel k as a two-pulse kernel, parameterized by the distance and the relative intensity between the primary and secondary reflections. We ignored higher order reflections as they carry minimal energy.
- In this case we have quantified Ghosting in Reflection layer only, not in transmitted one.

Toy Example

A synthetic example with a circle as the transmission layer and a rectangle as the reflection layer. We compare the log likelihoods of the various possible decompositions under a GMM Model. The log likelihood of the a) is the highest, (implying is most “Natural”) which is indeed the ground truth.

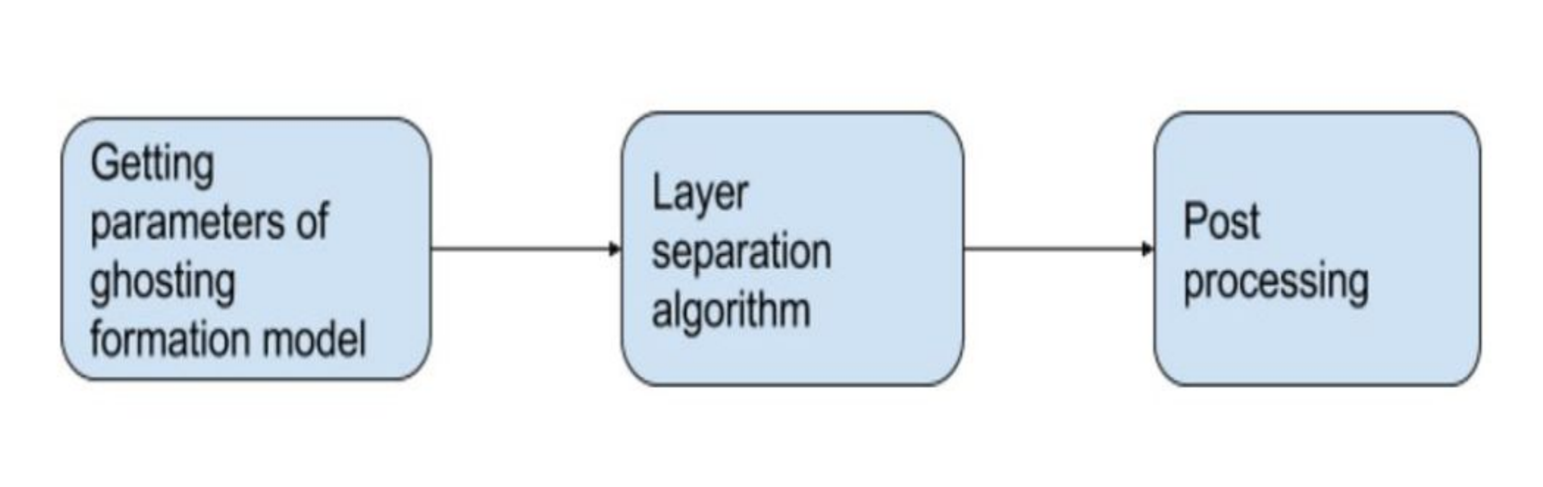


Why GMM ?

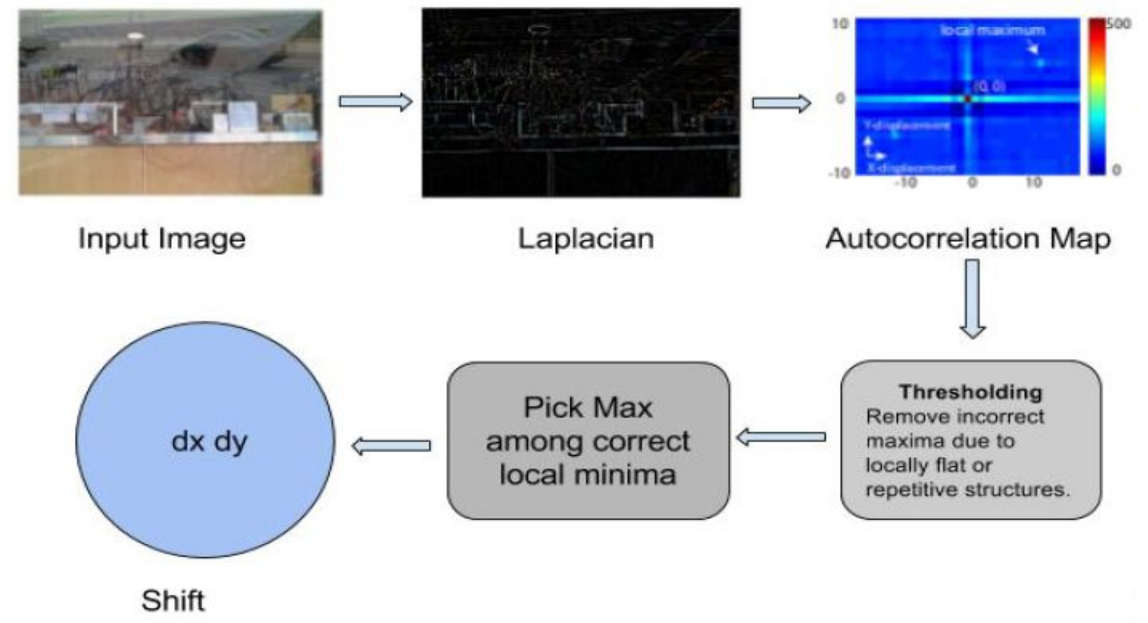
It performs well for image restoration when compared to other methods.

		Patch Restoration		Image Restoration	
Model	Log L	BLS	MAP	PA	EPLL
Ind. Pixel	78.26	25.54	24.43	25.11	25.26
MVG	91.89	26.81	26.81	27.14	27.71
PCA	114.24	28.01	28.38	28.95	29.42
ICA	115.86	28.11	28.49	29.02	29.53
GMM	**164.52**	**30.26**	**30.29**	**29.59**	**29.85**

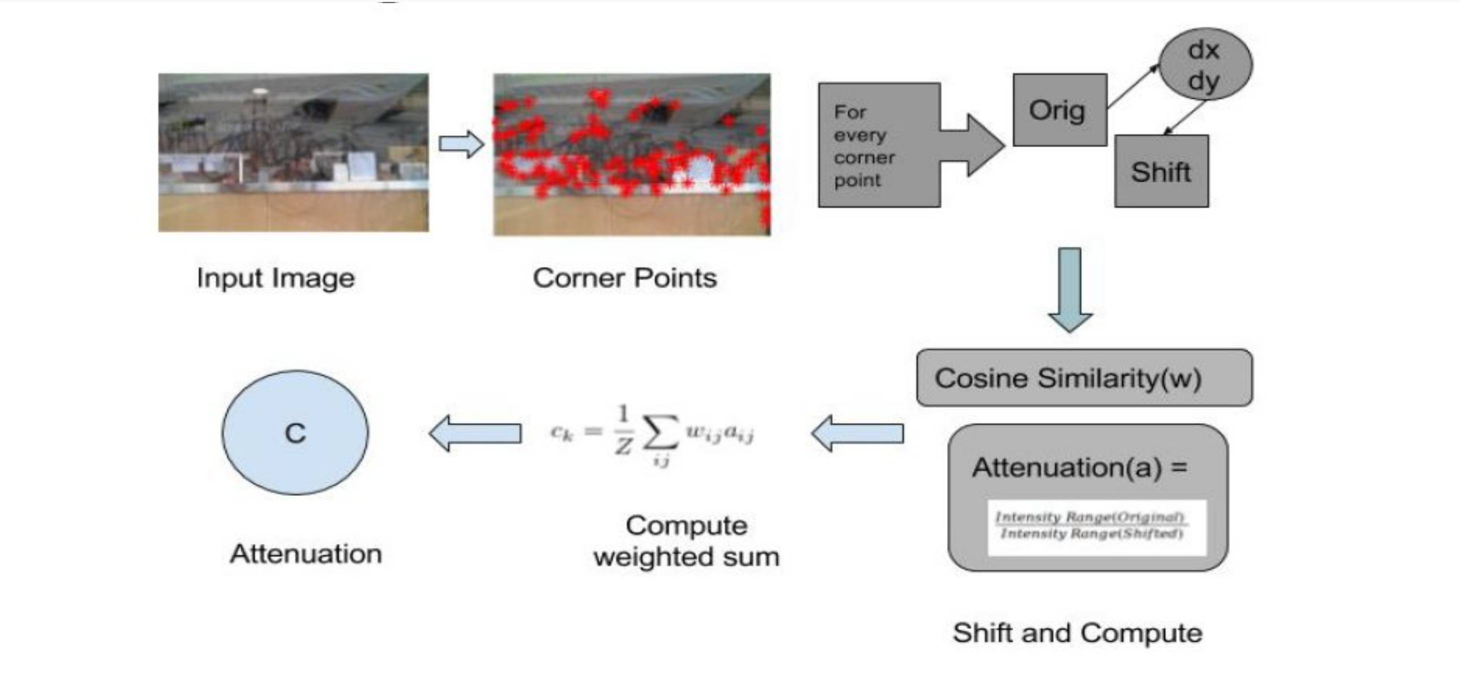
The BIG Picture



Estimating Kernel Parameters (d_k)



Estimating Kernel parameters (c_k)



Optimization

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

Minimizing COST:

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

Non Convex Due to GMM prior

Modelled as half quadratic optimization

Zit

Zir

Per Patch Auxiliary Variables

$$\min_{T,R,z_T,z_R} \frac{1}{\sigma^2}\|I-T-R\otimes k\|_2^2 \tag{7a}$$

$$+\frac{\beta}{2}\sum_i \left(\|P_iT-z_T^i\|^2+\|P_iR-z_R^i\|^2\right) \tag{7b}$$

$$-\sum_i \log(\mathrm{GMM}(z_T^i))-\sum_i \log(\mathrm{GMM}(z_R^i)) \tag{7c}$$

$$\text{s.t. } 0\le T,R\le 1 \tag{7d}$$

Alternating minimization

25 times

Solve for T and R → Naturalize or Restore T and R → Update Auxiliary variables

Auxiliary variables fixed

zit zir

Solve using LBFGS

$$\min_{T,R,z_T,z_R} \frac{1}{\sigma^2}\|I - T - R \otimes k\|_2^2 + \frac{\beta}{2}\sum_i \left(\|P_i T - z_T^i\|^2 + \|P_i R - z_R^i\|^2\right)$$

$$\text{s.t. } 0 \leq T, R \leq 1$$

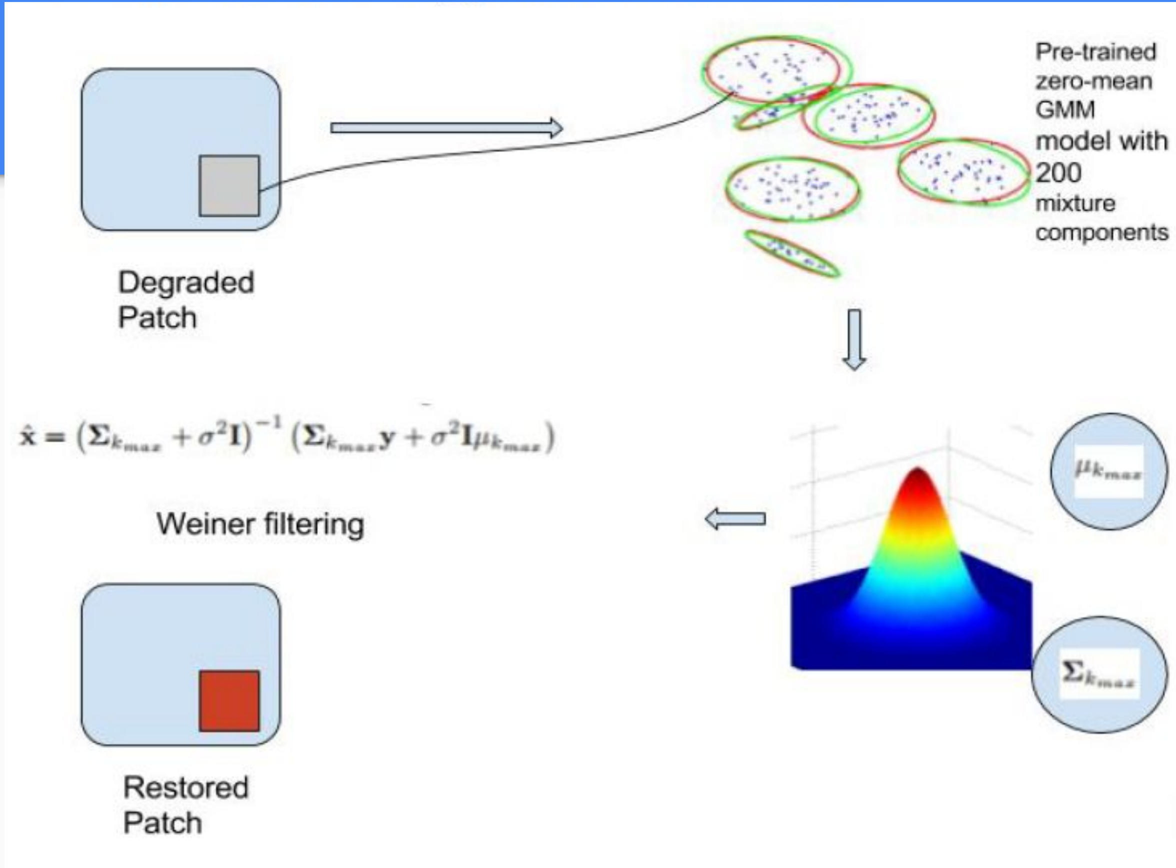
Solve using Estimated Patch log likelihood (EPLL)

$$-\sum_i \log(\mathrm{GMM}(z_T^i)) - \sum_i \log(\mathrm{GMM}(z_R^i))$$

$$\frac{\beta}{2}\sum_i \left(\|P_i T - z_T^i\|^2 + \|P_i R - z_R^i\|^2\right)$$

As Beta tends to infinity, zix's need to be equated to pix's to get a finite product value

Estimated Patch Log Likelihood (EPLL)



Results

Input Image

Transmitted

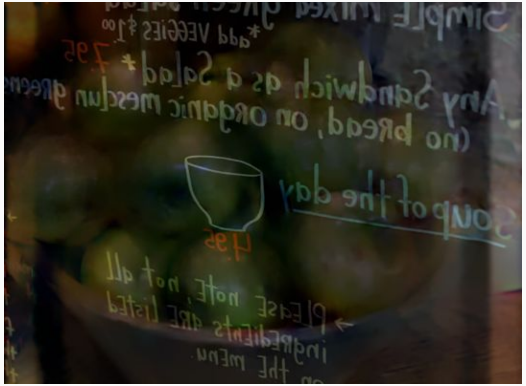
Reflected

Results (cont.)

Input Image

Transmitted

Reflected



Failure Cases

Input Image

Transmitted

Reflected

Limitations

- Requires double paned windows.
- It can fail on images with strong globally repetitive texture.
- We assume spatially-invariant ghosting.

- The reflection layer does not have large depth variations.
- When the angle between camera and glass normal is not too oblique.

Thank You