Reasoning about Photo Collections using Models of Outdoor Illumination

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Motivation

- Outdoor photo collections are rich in information, but difficult to reason about in part due to complexity of outdoor illumination. towards understanding the world through photo collections.
- Models of sun/sky illumination have been developed in the graphics community, but rarely leveraged in computer vision.

Contributions

- An analysis of the interactions between outdoor illumination and scene properties.
- A method for estimating ambient occlusion, albedo, and lighting in outdoor photo collections.
- A method for estimating the capture time of outdoor photos

Prior Work: Photometric Ambient Occlusion

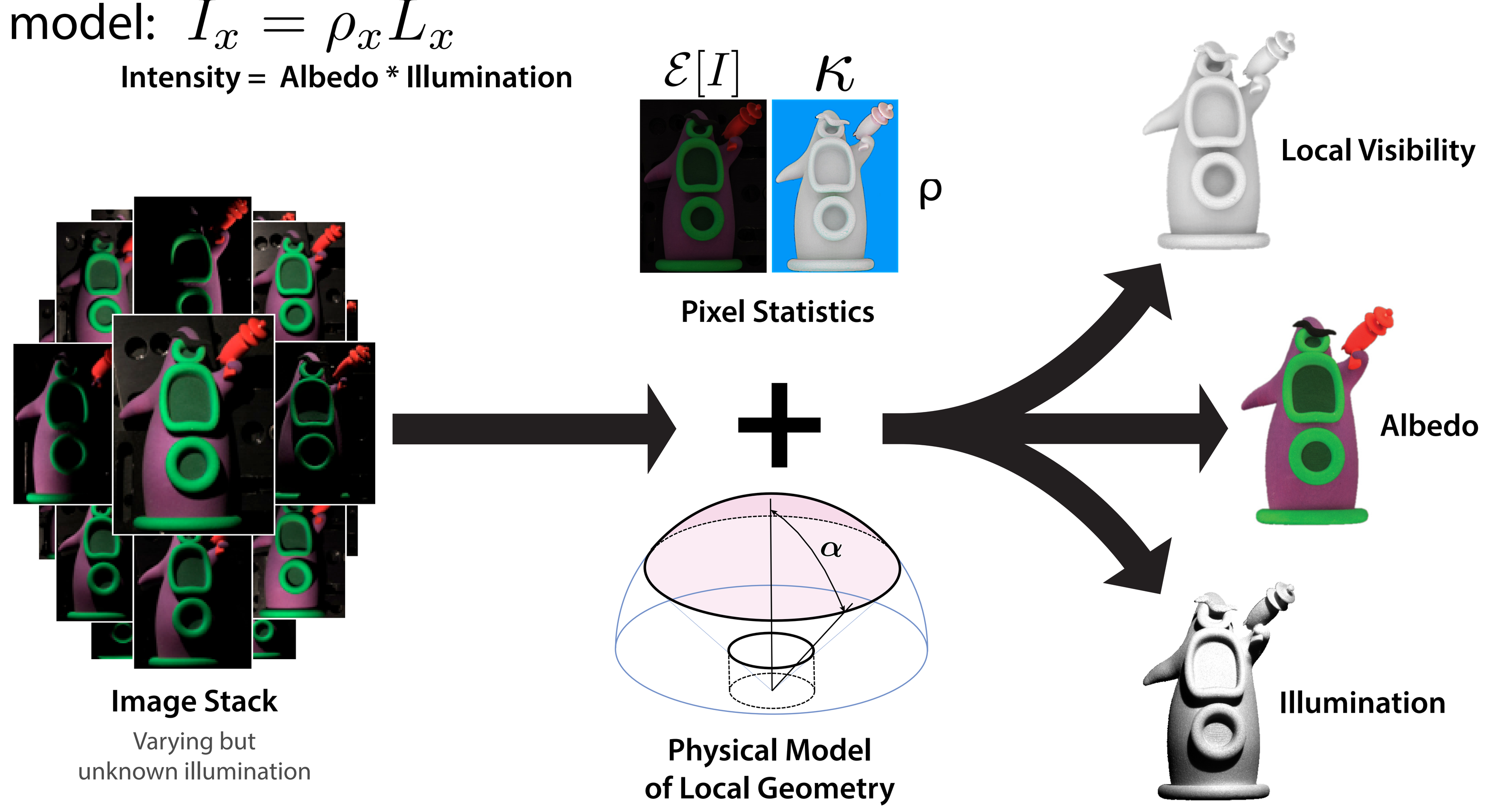
[Hauagge et al. CVPR 2013]

Albedo-invariant statistic:

$$\kappa = \frac{\mathcal{E}[I(x)]^2}{\mathcal{E}[I(x)^2]} = \frac{\mathcal{E}[\rho L]^2}{\mathcal{E}[\rho^2 L^2]} = \frac{\rho^2 \mathcal{E}[L]^2}{\rho^2 \mathcal{E}[L^2]}$$

Lambertian image formation model: $I_x = \rho_x L_x$

Intensity = Albedo * Illumination



Model local geometry as cylindrical crevice, parameterized by opening angle α

1. Estimate α:

   Analytically derive and invert $\kappa(\alpha)$, lookup observed κ

2. Estimate ρ:

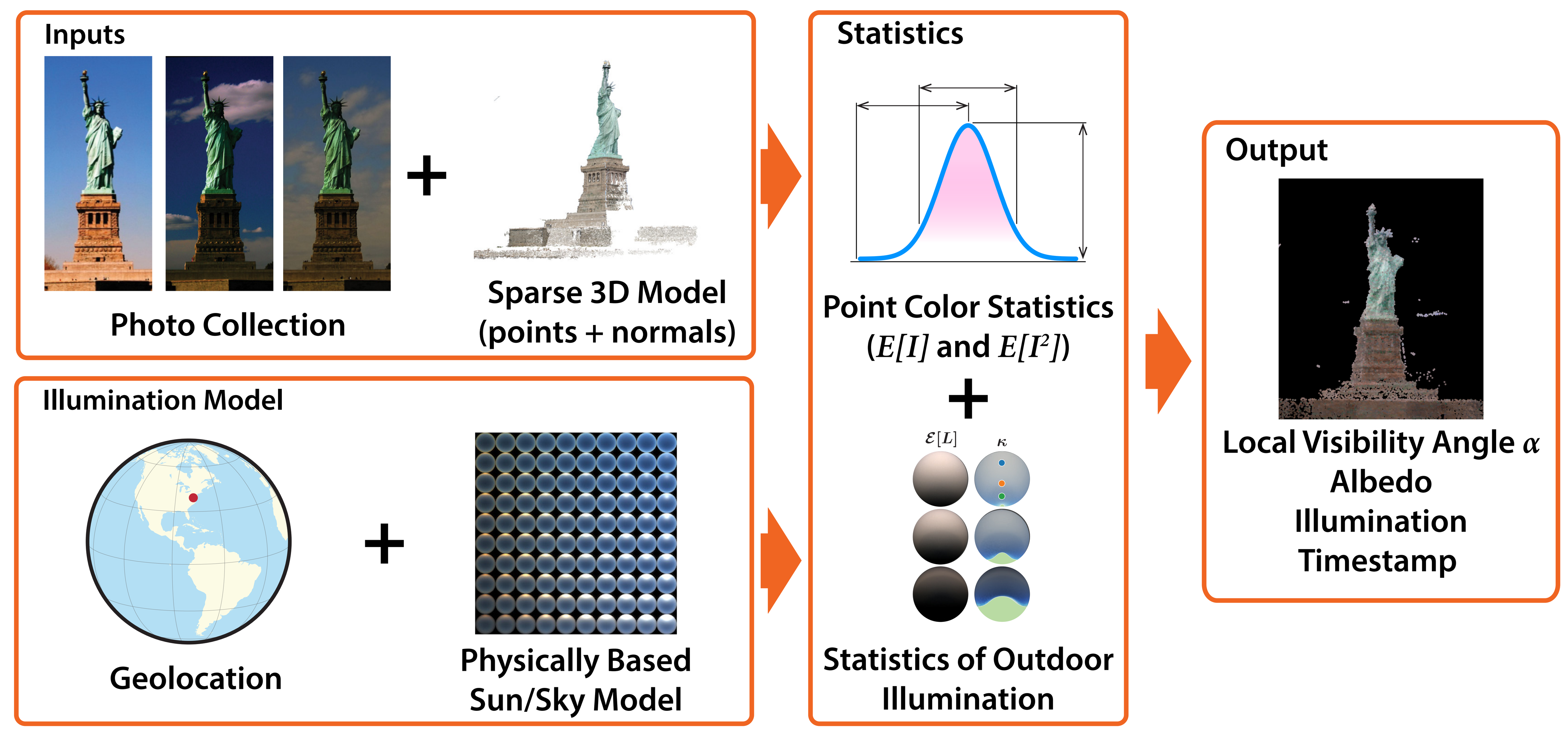
$$\rho = \frac{\mathcal{E}[I]}{\mathcal{E}[L(\alpha)]} \quad \begin{matrix}\text{(Observed)} \\ \text{(Predicted)}\end{matrix}$$

3. Estimate L:

$$L = \frac{I}{\rho}$$

Key limitation - lighting assumptions:
- Uniformly distributed point source
- Constant intensity and color
- Constant white ambient term

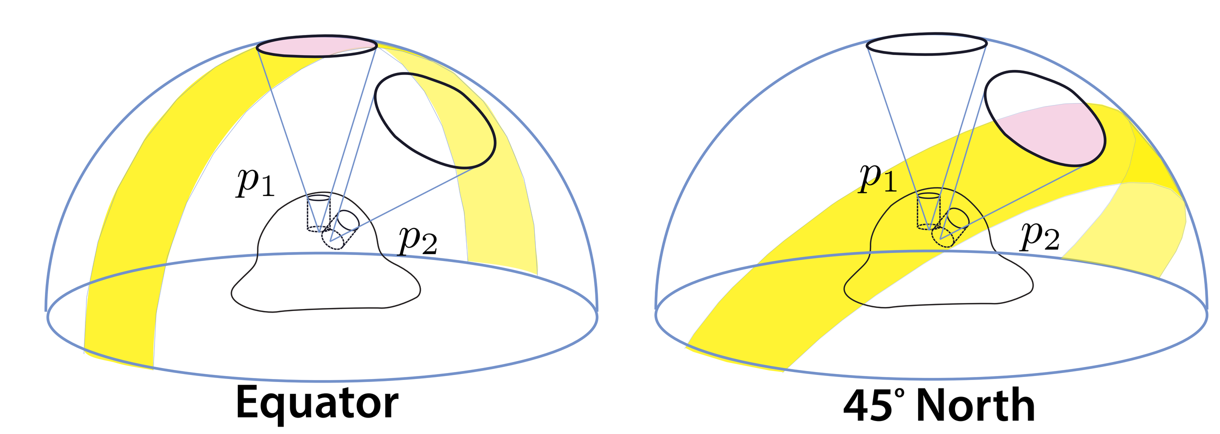
Algorithm Overview



Outdoor Illumination Model

Sun/sky illumination at a point is determined by:
- Geographic Location (ϕ, λ)
- Time and Date (t)
- Ambient Occlusion (α)
- Surface Normal $(\vec{n})$

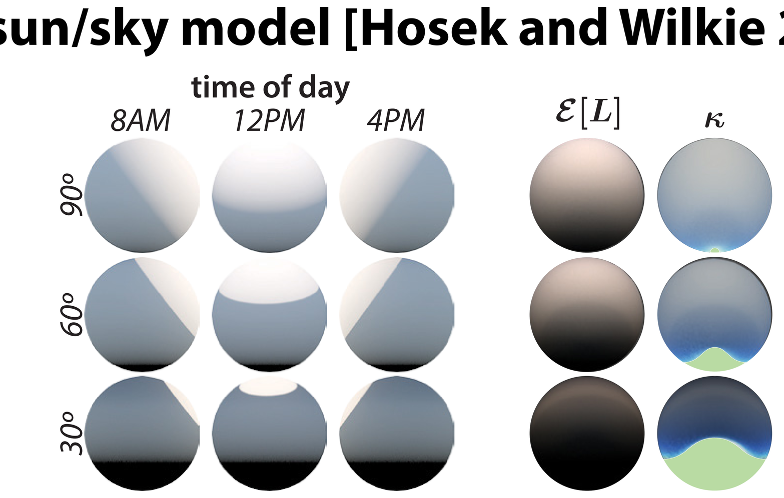
$$L(\phi, \lambda, t, \alpha, \vec{n})$$



Sun visibility is determined by geographic location, time of day and year, crevice depth, and surface normal.

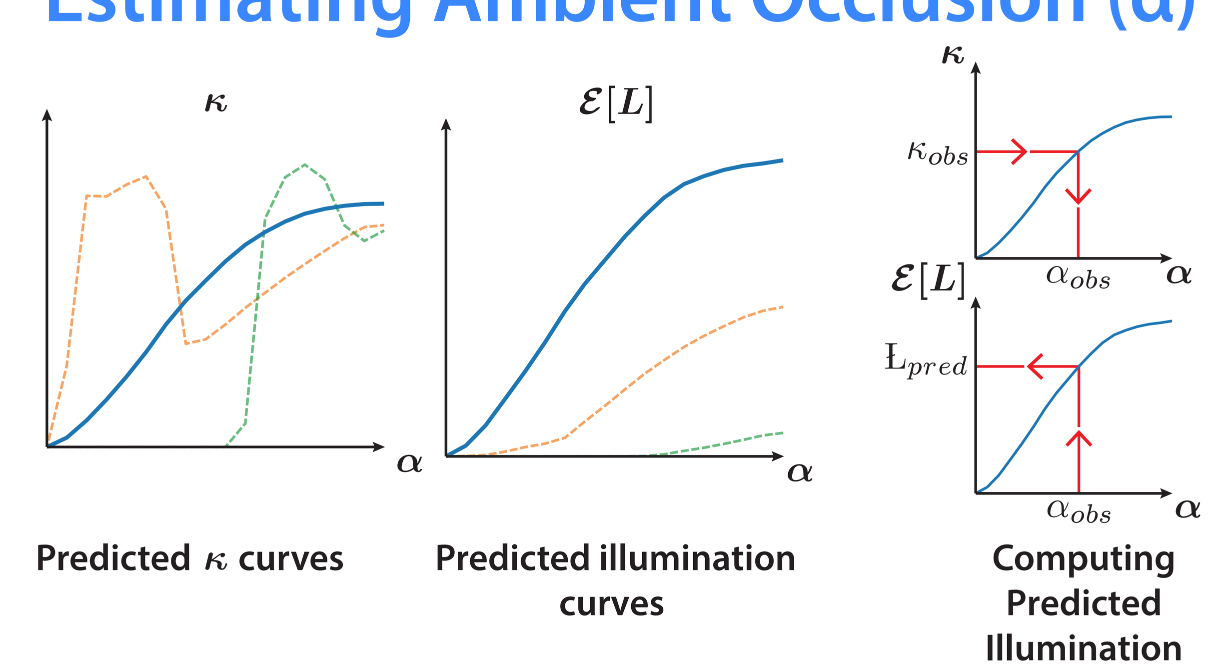
Estimating Albedo

Key Idea: Predict statistics of natural illumination using a physically-based sun/sky model [Hosek and Wilkie 2012]



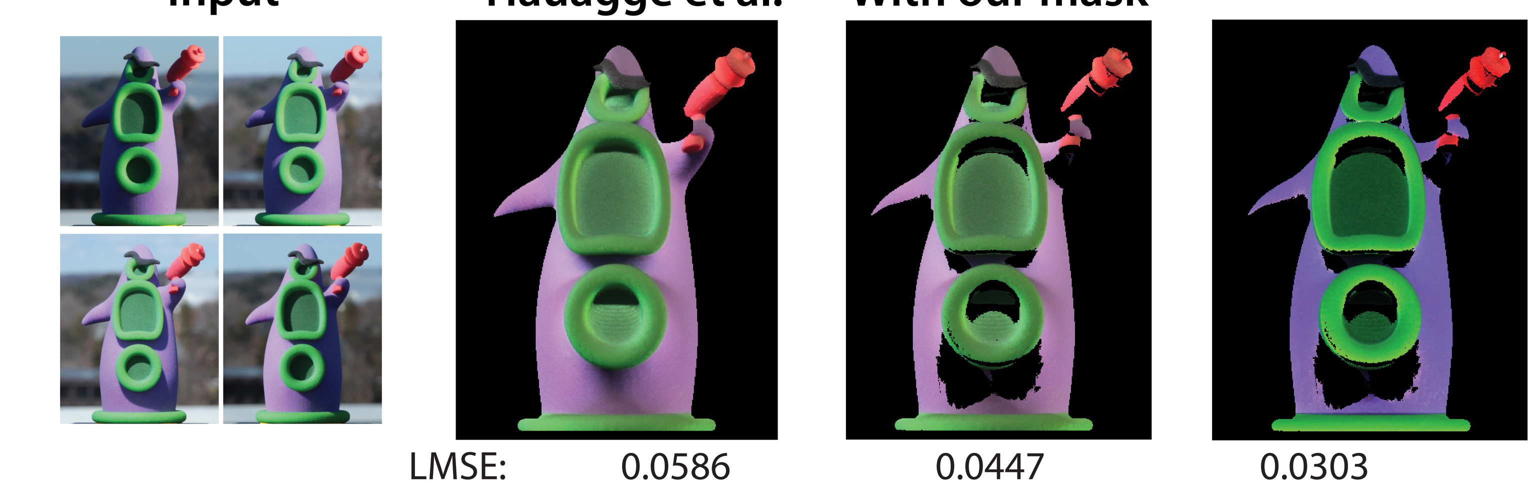
$$\rho = \frac{\mathcal{E}[I]}{\mathcal{E}[L(\phi, \lambda, t, \alpha, \vec{n})]} \quad \begin{matrix}\text{(Observed)} \\ \text{(Predicted)}\end{matrix}$$

Estimating Ambient Occlusion (α)



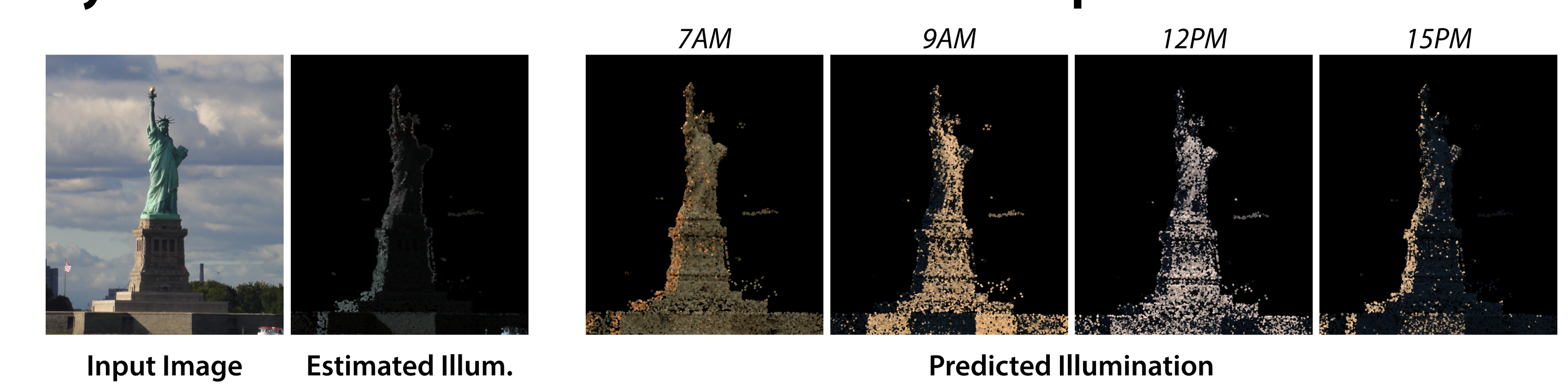
For an observed value of κ, we look up α and the predicted illumination E[L], which allows us to estimate the albedo.

Application: Intrinsic Image Decomposition



Application: Timestamp Estimation

Key Idea: Estimate illumination and find closest predicted illumination



Legend
t-sunsky: our method
t-unif: albedo from [Hauagge et al., 2013]
Rand: the average expected error of guessing a random time during the day
Exif: timestamp stored in image
LEN: method proposed in [Lalonde et al., IJCV2011]

Timestamp errors (in minutes)

Visualizing Timestamp Results