Webcam Clip Art: Appearance and Illuminant Transfer from Time-lapse Sequences

Yilin Yang, Shiyu Dong

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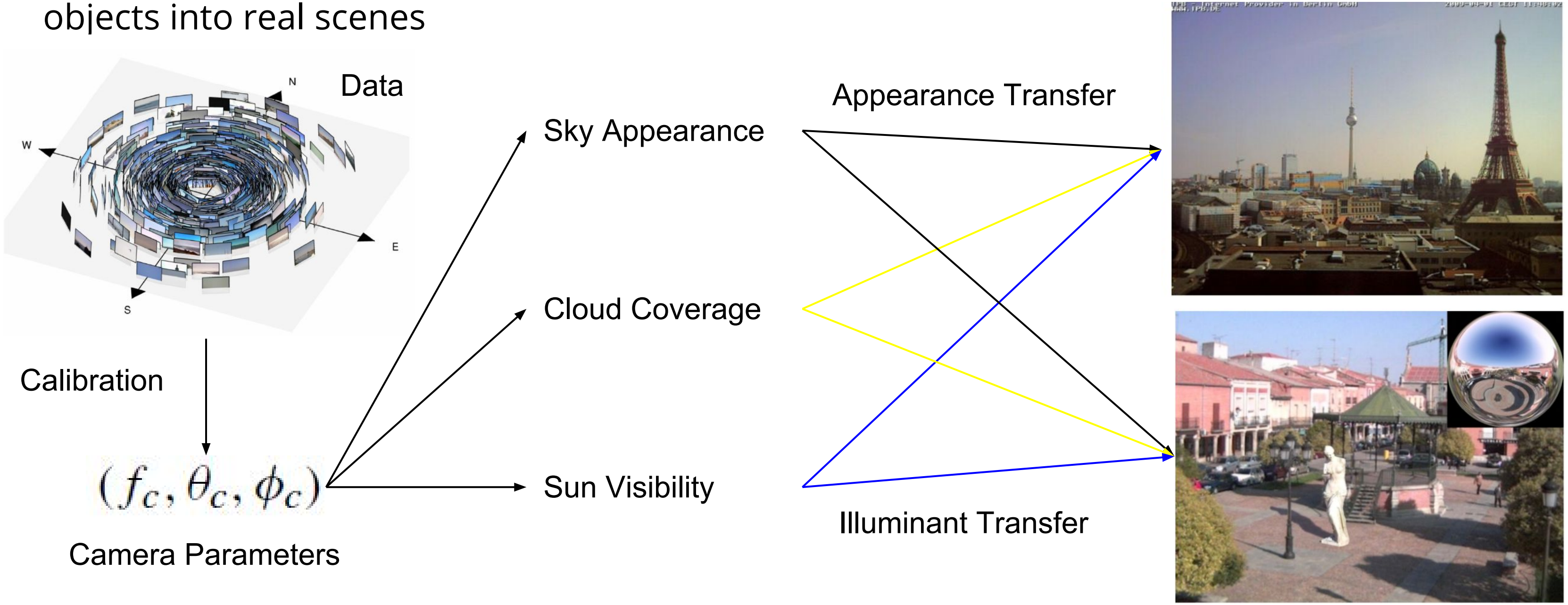
1. Overview

Goal: Based on natural illumination model, use large datasets of time-lapse sequences to

- <u>transfer appearance</u>: match various illumination of scenes and transfer the appearance information of objects onto the scene;
- <u>transfer illuminant</u>: relight scenes under different illumination conditions & insert virtual objects into real scenes



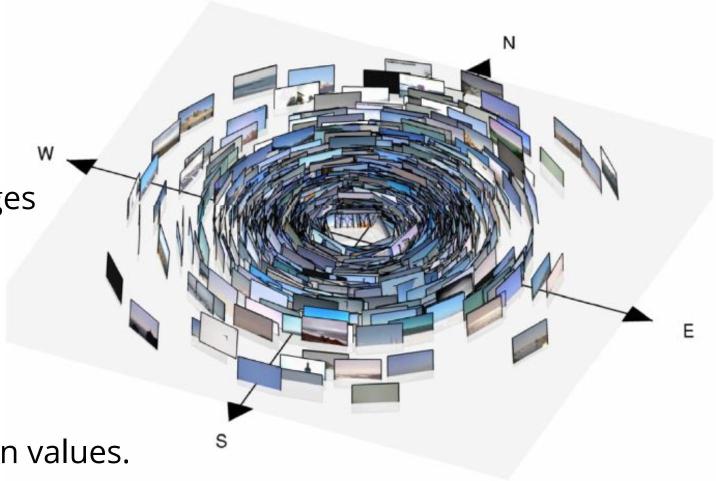
2. Building a webcam database

high resolution, stationary, calibrated

1. **Data collection:**

   Designed system that crawls webcams.travel to find webcam sequences with:
   - High resolution (at least 640*480)
   - Visible sky (geometric context algorithm [Hoiem et al. 2005])
   - Static camera (translation of SIFT feature points [Lowe 2004])

2. **Radiometric calibration**
   - Estimate the inverse camera response function by using color edges [Lin et al. 2004]
   - Input: image intensity
   - Output: Scene radiance



3. **Geometric calibration**
   - If the sky is clear, the weather coefficients (a,b,c,d,e) take on known values.
   - The sky model is a function of f_c, θ_c, ϕ_c
   - Input: Clear sky images, GPS location of the camera, the Date and time of capture of each image
   - Output: Camera parameters: f_c, θ_c, ϕ_c

➔ *1350 suitable webcams from five continents, a total of over 1.2 million images*

3. Natural Illumination Model

(1) Perez Sky Model [Perez et al. 1993]

Relative luminance: $l_p = f(\theta_p, \gamma_p) = [1 + a\exp(b/\cos\theta_p)] \times [1 + c\exp(d\gamma_p) + e\cos^2\gamma_p]$

Absolute luminance: $L_p = L_z \frac{f(\theta_p, \gamma_p)}{f(0, \theta_s)}$

(2) Camera Geometry from Clear Skies [Lalonde et al. 2009]

Angle of the segment: $\gamma_p = \arccos\left(\cos\theta_s \cos\theta_p + \sin\theta_s \sin\theta_p \cos(\phi_p - \phi_s)\right)$

Zenith angle of the segment: $\theta_p = \arccos\left(\frac{v_p \sin\theta_c + f_c \cos\theta_c}{\sqrt{f_c^2 + u_p^2 + v_p^2}}\right)$

Express the relative luminance as: $l_p = g(u_p, v_p, \theta_c, \phi_c, f_c, \theta_s, \phi_s)$

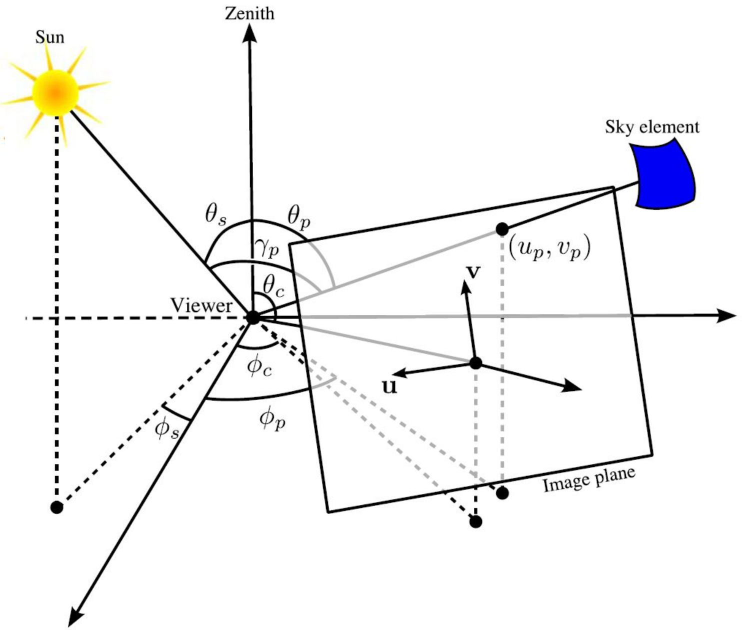
Given GPS and time, we calculate sun zenith and azimuth (θ_s, ϕ_s)

For clear skies, we know the value of a, b, c, d, e

$y_p^{(j)}$ is the intensity at pixel (u_p, v_p) in image j

Minimize $\min_{\theta_c, f_c, \phi_c, k^{(j)}} \sum_{j \in \mathcal{J}} \sum_{p \in \mathcal{P}} \left(y_p^{(j)} - k^{(j)} g(u_p, v_p, \theta_c, \phi_c, f_c, \theta_s, \phi_s)\right)^2$

to get camera parameters (f_c, θ_c, ϕ_c)



3. Natural Illumination Model

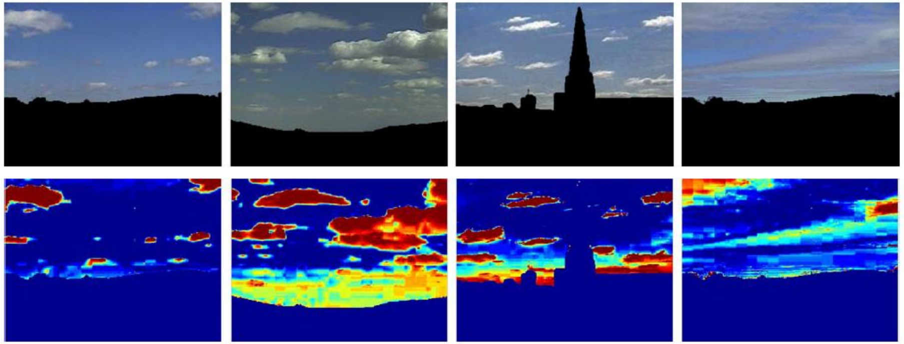
(3) Sky Appearance [Lalonde et al. 2009]

Minimize $\min_{\mathbf{x}} \sum_{l=1}^{3} \sum_{p \in \mathcal{P}} w_p \left(y_p^{(l)} - k^{(l)} g(u_p, v_p, \theta_s, \phi_s, \tau^{(l)}(t)) \right)^2 + \beta \|\mathbf{x} - \mathbf{x_c}\|^2$ over $\mathbf{x} = [t \; k^{(1)} \; k^{(2)} \; k^{(3)}]$

$\tau^{(l)}(t)$ represents a, b, c, d, e obtained by $M^{(l)}$: $\tau^{(l)}(t) = M^{(l)}[t \; 1]^T$ where t is turbidity [Preetham et al. 1999]

(4) Cloud Coverage [Lalonde et al. 2009]

Cloud layer: $\frac{1}{|\mathcal{P}|} \sum_{p \in \mathcal{P}} w_p$



(5) Sun Visibility

Compute the ratios of saturation and value of the current image w.r.t the mean image

- Sun is not visible: a dominant peak near (1, 1) in the joint histogram;
- Sun is visible: multiple peaks or a wider spread in the joint histogram.

Sun visibility coefficient s_{vis}: the proportion of nearest neighbors with fully visible suns

- χ^2 distance for the joint histogram features

4. Appearance Transfer

1. **Matching Scene using weighted attributes**

$$M = w_1 \angle(\Delta\phi^i, \Delta\phi^j) + w_2 \angle(\theta_c^i, \theta_c^j) + w_3 w_z \angle(\theta_s^i, \theta_s^j) +$$
$$w_4 \chi^2(V^i, V^j) + w_5 D(C^i, C^j) + w_6 D(t^i, t^j)\,,$$
$$w_1 = 2,\ w_2 = 1.5,\ w_3 = 1.5,\ w_4 = 1.5,\ w_5 = 1,$$

- The camera azimuth angle relative to sun $\Delta\phi = (\phi_c - \phi_s)$
- The camera zenith angles θ_c
- The sun zenith angles θ_s
- The visibility of the sun C
- The turbidity in the atmosphere t
- The cloud coverage (the norm $||C||$ of the cloud layer)

2. Re-coloring according to the scene colors to compensate for color differences between cameras. [Reinhard et al. 2001]

3. Add constraint for intensity differences.

- Compute the mean histogram of scene intensity differences for all adjacent frames
- Penalize images whose intensity difference differs from the mean histogram

4. Appearance Transfer

(a) Object transfer (building)

(b) Object transfer (Eiffel tower)

5. Illuminant Transfer

(1) Sky Probe

- Sky layer
- Cloud layer
- Sun layer [Stumpfel et al. 2004]

Sun appearance: rotate the sky probe so that all the sun locations are at the origin

$$s(\theta_s) = s_{max} s_{vis} \frac{\alpha \exp(-\beta m(\theta_s))}{\alpha \exp(-\beta)}$$

Relative optical path length through Earth's atmosphere [Kasten and Young 1989]:

$$m(\theta_s) = \frac{1}{\cos(\theta_s) + 0.50572(96.07995 - \frac{180}{\pi}\theta_s)^{-1.6364}}$$

(2) Environment Map [Khan et al. 2006]

Map the pixels below the horizon line in the image onto the bottom hemisphere
Find all non-sky objects above the horizon and project them onto a cylinder

(3) Relighting virtual objects [Debevec 1998]

Synthesize the object according to the light intensities specified in our estimated environment maps

(4) Relighting in a single image [Horry et al. 1997]

Using ray tracing algorithm to relight the scene with the new sky probe

5. Illuminant Transfer

Relighting Virtual Objects

Relighting a Single Image

6. Conclusion

Overall rating: 2 (1 definite accept, 5 definite reject)

Contributions:

1. Build a big webcam database for appearance and illuminant transfer
2. Several fascinating applications based on the illumination model
3. Optimize turbidity, rather than 5 coefficients, to constrain the appearance model
4. Consider sun visibility when analyzing illumination conditions
5. Come up with a measurement to match illumination across scenes

Limitations:

1. The weights for matching illumination across scenes are fixed by human. Try to learn the weights using machine learning.
2. If there are no similar weather conditions in the dataset, appearance transfer cannot be applied. Moreover, it's hard to match and relight rare illumination conditions like storms and fog.
3. Can't transfer/generate shadows for 2D appearance transfer.
4. For 3D illumination transfer, the rendering engine can generate shadows, but it can only be on the ground plane (without casting shadows on other objects)
5. When relighting a single image, the weather must be overcast.

Related Work

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- Lalonde, Jean-François, et al. "Photo clip art." ACM transactions on graphics (TOG) 26.3 (2007): 3.
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- Stumpfel, Jessi, et al. "Direct HDR capture of the sun and sky." *Proceedings of the 3rd international conference on Computer graphics, virtual reality, visualisation and interaction in Africa*. ACM, 2004.
- Kasten, Fritz, and Andrew T. Young. "Revised optical air mass tables and approximation formula." *Applied optics* 28.22 (1989): 4735-4738.
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- Horry, Youichi, Ken-Ichi Anjyo, and Kiyoshi Arai. "Tour into the picture: using a spidery mesh interface to make animation from a single image." *Proceedings of the 24th annual conference on Computer graphics and interactive techniques*. ACM Press/Addison-Wesley Publishing Co., 1997.

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