Incorporating Cloud Distribution in Sky Representation

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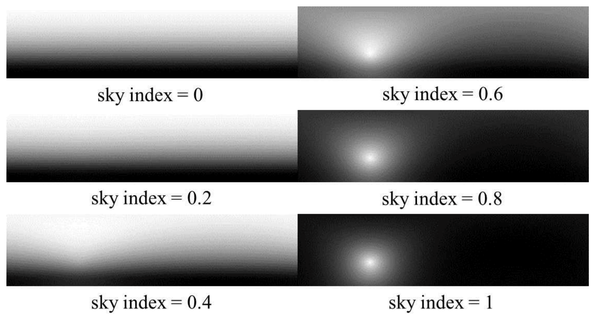
Motivation

Most sky models only describe the cloudiness of the overall sky by a single category or parameter such as sky index, which does not account for the distribution of the clouds across the sky.

Contributions

1. Extend sky index to a per-pixel level.
2. Better geo-locating ability.
3. Sky re-rendering at any time and location.

Igawa Sky Model



The horizontal axis is azimuth angle (0 to 360 degrees from left to right), and the vertical axis is altitude from horizon to nexus (0 to 90 degrees from bottom to top). Sky index ranges from 0 (overcast) to 1 (clear) representing the degree of cloudiness. In this case, the solar azimuth and altitude are 90 and 30 degrees respectively. Each sky map is scaled between 0 (black) and 1 (white) for display.

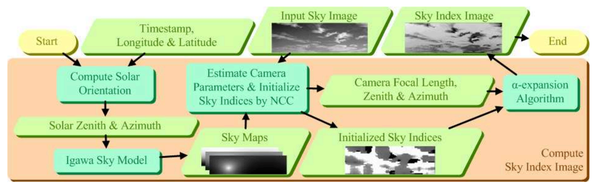
AMOS Data Set

Among 633 cameras with the ground truth location data in the AMOS data set, we choose 198 images from different cameras taking pictures where the sky occupies at least one-third of the entire image.

References

[1] N. Igawa et al. Models of Sky Radiance Distribution and Sky Luminance Distribution In *Solar Energy 2004*
[2] N. Jacobs et al. Webcam Geo-localization Using Aggregate Light Levels In *WACV 2011*
[3] Q. Li et al. Thin Cloud Detection of All-sky Images Using Markov Random Fields In *Geosci. Remote Sensing Lett. 2012*
[4] A. J. Preetham et al. A Practical Analytic Model for Daylight In *SIGGRAPH 1999*

Calculating Sky Indices



$$E(l) = \sum_{s_i \in S} \psi_i(SI_i) + \sum_{s_i \in S, s_j \in N(s_i)} \psi_{ij}(SI_i, SI_j) \quad (1)$$

$$\psi_i(SI_i) = \underbrace{c_1 - NCC(s_i, SI_i)}_{\text{inconsistency with the Igawa sky model}} + \underbrace{c_2 |I_r(s_i) - I_n(s_i)|}_{\text{reconstruction error}} \quad (2)$$

$$\underbrace{\psi_{ij}(SI_i, SI_j)}_{\text{contrast sensitive Potts model}} = \begin{cases} 0 & \text{if } SI_i = SI_j \\ h(i,j) & \text{otherwise} \end{cases} \quad (3)$$

$$h(i,j) = c_3 + c_4 \cdot \exp\left(-c_5 \cdot \|I_c(s_i) - I_c(s_j)\|^2\right) \quad (4)$$

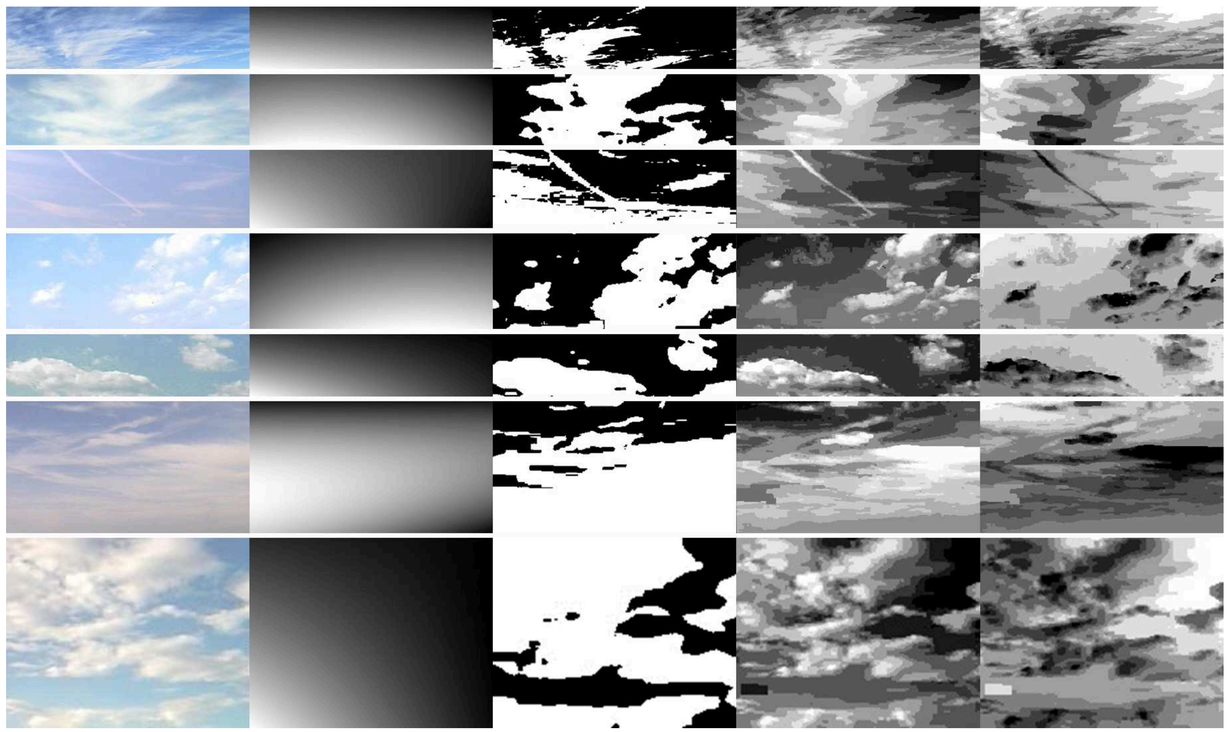
Symbol	Explanation
S	the set of all sky pixels s_i
N	the neighborhood system
SI_i	the sky index of the sky pixel s_i
L	the label set
l	a labeling of all sky pixels ($l \in L^{\lvert S \rvert}$)
c_i	empirically determined constants

Demonstration of α-expansion algorithm.

Sky Image Re-rendering

Reconstructed sky images with the same cloud distribution under various time and locations. The chromatic information in these images is kept the same as that of the input image without introducing another scattering model.

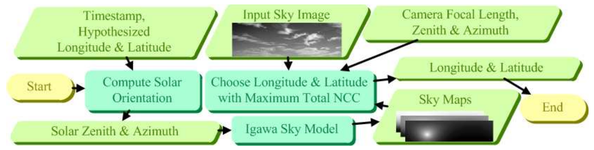
Results

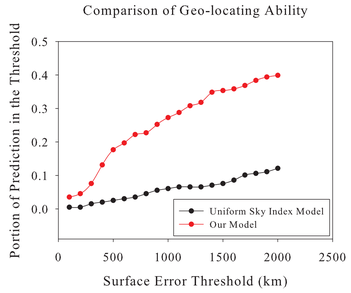


(a) input sky images (b) uniform model (c) Li's method (d) our model (e) our sky index images

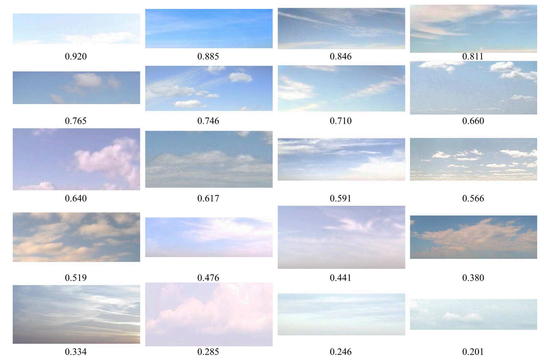
The reconstructed images using the uniform sky index model and our proposed model (one example per row). Column (a) is the input sky images taken from the AMOS data set. Column (b) and (d) are the reconstructed sky images (brighter pixels indicate higher sky intensity) with the uniform sky index model and our model respectively. Column (c) is the results of thin cloud detection using Li's method where white (black) pixels represent clouds (sky). Column (d) is reconstructed from column (e), the sky index images of our model, where clearer sky pixels are brighter.

Geo-location Estimation





Cloud Cover Estimation



The estimation of cloud cover by our model. Each number is the average sky index ranging from 0 (overcast) to 1 (clear) of the corresponding image.