The Clear Channel Prior

Authors: Devorah Langsam

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Capturing imagery from outdoor cameras provides a large amount of information about a scene. The true surface appearances of elements in a scene, however, are often incorrectly represented in images. To get a better representation of the scene it is necessary to separate the effects of the underlying reflectance, illumination, and fog in the image. The goal of the dark channel prior is to eliminate the effects of haze in outdoor images and recover the true surface reflectance image for the scene. The reflectance of an image is the actual color information of a scene when the effects of lighting have been removed. Images of outdoor scenes were taken from several cameras from AMOS: http://amos.cse.wustl.edu/dataset. Sets of 30 images of the same scene in varying weather conditions were used in the clear channel prior algorithm in order to provide enough variety of data for each scene.

Sample images:
Scenes are outdoor and include varying degrees of fog
The problem of estimating the scene reflectance based on imagery has a long history. These can be loosely separated into methods that focus on a single image, and (the larger) set of methods that consider multiple images.

Yair Weiss attempts to solve for the reflectance of a scene given several images of the same scene taken under different lighting. For any input image \( I(x, y) \), it can be decomposed into the reflectance image, \( R(x, y) \), and illumination image \( L(x, y) \). The equation \( I(x, y) = L(x, y)R(x, y) \) is under constrained when using only one input image. Yair Weiss makes the assumption that given multiple images of the same scene the reflectance does not change. He also notes that image derivative filters result in filter outputs that are sparse.

In order to find the reflectance, Yair Weiss works in the log domain, because the relationship between the log of the reflectance image and the log of the illumination image is additive. He begins by applying filters in both the x and y direction to the natural log of the images. If the reflectance was known, these same filters could be applied to the reflectance image as well. Because it is unknown, Yair Weiss estimates the reflectance by taking the median results of the filtered outputs in both directions. By taking the median, any sporadic lighting effects drop out. Yair Weiss then uses the median filtered outputs and the known filters to solve for what the reflectance image would be and raises e to these results to leave the log domain.
Example results taken from Yair Weiss paper. The algorithm was applied using a set of 35 images of the same scene.

When looking at a single image, it is challenging to remove the effects of haze because haze is dependent on depth information that cannot be calculated with only one image. The dark channel prior is a method to remove haze from a single image under the assumption that most parts of a haze free outdoor image will consist of some pixels that have low intensity in at least one of the three-color channels. The algorithm begins by first removing the sky region of the image because the previous observation of low intensity pixels does not hold in the sky. Then for each pixel the algorithm calculates the minimum pixel intensity among all three color channels in a patch of size 15 x 15 around the pixel. The minimum pixel intensity calculated at each pixel is subtracted from each color channel of that pixel to remove the effects of haze.
Both the Dark Channel Prior and Yair Weiss’s algorithm begin to solve the problem of removing fog and finding the reflectance image, but neither methods yield a convincing result of what the true reflectance of a scene that includes images with a lot of haze as input looks like. Yair Weiss’s method on its own produces reflectance images that appear faded. Applying the dark channel prior to each image before computing the reflectance image with Yair Weiss’s method is not very successful. The results seem oversaturated and unnatural.

The clear channel prior attempts to solve the problem of removing haze from images and solving for the reflectance, under the assumption that given a set of images for each pixel some image should be clear. The approach to finding that clear pixel is to select an appropriate largest gradient at the pixel to constrain the true
reflectance. Larger gradients represent more contrast between pixels, which occurs in images with less haze. This method is successful because some images will have better representations of different parts of scene depending on whether haze is affecting these parts. It is important to note that taking just the biggest overall gradient at each pixel is not a viable option because the gradient may not be representative of the true scene. Therefore an appropriate large gradient that points in the right direction must be selected.

The algorithm is as follows:

Given: n images of the same scene

Compute the single true reflectance image

1) Read in the \( n \) images into array \( I_m \)
2) Separate \( I_m \) into the red, green and blue color channel

For all 3 color channels:

3) Take the natural log of the images

At each pixel \((x, y)\) in the image in each image \( n \):

4) Calculate the x and y derivatives \( d_x(s, x, y, n) \) and \( d_y(s, x, y, n) \).
5) Normalize each vector

\[
V_{trLength} = 0.01 + \sqrt{d_x(s, x, y, n)^2 + d_y(s, x, y, n)^2}
\]

\[
V(x, y, n, 1) = \frac{d_x(s, x, y, n)}{V_{trLength}}
\]

\[
V(x, y, n, 2) = \frac{d_y(s, x, y, n)}{V_{trLength}}
\]

6) Calculate the angular difference between all vector pairs.
7) Choose the tightest clump of vectors and select the longest vector in this group.

Let \( j \) be the image that corresponds to this vector.

8) Let \( dx \) and \( dy \) at pixel \((x, y)\) equal \( d_x(s, x, y, j) \) and \( d_y(s, x, y, j) \) respectively.
9) Use \( dx \) and \( dy \) solve for the reflectance image.
10) Recombine the 3 color channels to form reflectance image \( r \).
11) Calculate \( e^r \) to leave the logarithmic domain and recover \( R \).
This picture illustrates step 6 and 7 where the gradients at a pixel for each image is taken and the largest gradient within the tightest clump is selected to represent the derivatives at that pixel.

As a default, when looking at a set of 30 images the largest gradient in the tightest clump of 10 vectors is chosen. However, for some pixels there is no tight clump of 10 vectors. In these cases a largest angle in a smaller clump is selected. The consideration of whether vectors were considered close enough can be adjusted. Different angle thresholds for considering vectors close together and finding a clump resulted in different reflectance results.
The upper left hand image is the result applying the general find the largest clump of 10 gradient rule. The subsequent images show thresholds for close angles of $\pi/2$, $\pi/3$, $\pi/4$ and $\pi/6$. The lower right hand image is the result of Yair Weiss’s method.

The clear channel prior yields higher contrast results than Yair Weiss’s method of taking the median gradients to solve for the reflectance. As the angle threshold increase, more details in the scene are visible. For example the colors of the mountain are more vivid and the outlines of the shrubs on the ground are more visible when two vectors with an angle greater than $\pi/4$ between them are considered far apart.

There are some limitations to this method. It relies on the existence of a variety of images and that for each pixel some of these images will be clear. If all the input images were on very foggy days, it would not be able to remove the effects of haze. There is the risk that taking too small of an angle threshold could eventually result in including derivatives that violate the sparse assumption of filter outputs and include lighting effects. The correct angle threshold may vary depending on the
scene and input images. Another area to explore in the future is the possibility of applying the method on a larger scale instead of examining each pixel. It is likely that the largest gradients came from a few images that were on clear days and therefore each pixel would not need to be examined independently.

![Reflection with 20th gradient](image1)

![Reflection with large angles removed > π/2](image2)

![Reflection with large angles removed > π/3](image3)

![Reflection with large angles removed > π/4](image4)

![Reflection with large angles removed > π/6](image5)

![Reflection with Median](image6)

Additional results of the clear channel prior.