INDIAN INSTITUTE OF INFORMATION TECHNOLOGY, NAGPUR

Digital Signal Processing (ECL-301)

Project on Visibility Enhancement With Single Image Fog Removal

Under the Guidance of

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Visibility Enhancement With "Single Image Fog Removal"

1.1 Abstract: When the images are captured in a bad weather like fog and haze, it leads to whiten the image as well as lowers the contrast. The reason behind this is scattering of light through dust and smoke particles in atmosphere. In this project we are going to eliminate the fog by estimated transmission map, so that the characteristics of the image can be improved. Implementation is done on MATLAB.

1.2 Introduction: Fog removal is very important in various applications like surveillance, automated vehicles, object recognition etc., and it has been very challenging. Low visibility is considered as main cause of the increasing number of accidents. When extreme weather conditions exist mainly due to fog, haze, darkness, etc., the driver is unable to see a distinct view of roads. It's natural that it decreases the contrast and color fidelity of objects in the captured image and makes the object hard to see through our eyes. This project is done on the algorithm which preserves sharp details and maintains the color quality of the defogged image. There are many approaches in which characteristics of image can be improved according to the requirement. In this project we are going to choose the best approach for defogging the foggy image.

1.3 Methodology: Since last two decades many image fog removal approaches have been proposed. Mainly they are of three types. Refer to the table below.
Above all of these techniques we preferred Dark Channel Prior because,this algorithm is derived from the characteristic of natural outdoor images that the intensity value of at least one color channel within a local window is close to zero. Based on this,dehazing is accomplished through four major steps:

1. Atmospheric light estimation
2. Transmission map estimation
3. Transmission map refinement
4. Image reconstruction.

This dehazing process provide a step-by-step approach to the complex solution of the problem.

Single-image dehazing approach	**Multiple image dehazing approach**	**Additional information dehazing approach**
It relies upon statistical assumptions to recovers the scene information based on the proceeding information from a single image. Its main purpose is to improve the contrast ratio of the image . Categories: 1. Contrast maximization 2. Independent component Analysis 3. Dark Channel Prior	Involves multiple images to eliminate haze from the degraded images and to determine depth of the scene. Categories: 1. Method based on different weather condition 2. Method based on Polarization 3. Depth map-based method	Involves scene information to eliminate haze and restore the color fidelity.

1.4 Dark Channel Prior Algorithm:

1. Kaiming has proposed this algorithm for the first time.
2. There are dark pixels whose intensity values are very close to zero for at least one color channel within an image patch. Based on this, a dark channel is defined.
3. From 5000 dark channels of outdoor haze-free images, it was demonstrated that about 75 percent of the pixels in the dark channels have zero values and 90 percent of the pixels have values below 35 when the pixels in the sky region are excluded.
4. The dark channel is first constructed from the input image.
5. The atmospheric light and the transmission map are then obtained from the dark channel
6. The transmission map is further refined.
7. The haze-free image is finally reconstructed.

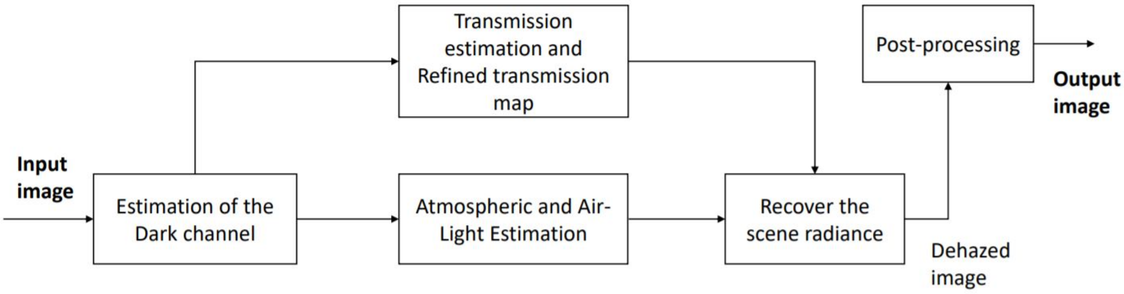

Figure 1: Block Diagram

1.5 Procedure:

1. Global representation of foggy image,

$$I(x) = J(x).t(x) + A(1 - t(x)) \tag{1}$$

where,
I(x) = Input Image
J(x) = Output Image
t(x) = Transmission within a medium representing the fraction of light reaching the camera without being scattered.
A = Global Air light

2. In the homogenous atmosphere, the transmission is expressed as,

$$t(x) = e^{\beta d(x)} \tag{2}$$

β = Scattering coefficient of atmoshere
The transmission t(x) is also written as,

$$t(x) = \frac{||A - I(x)||}{||A - J(x)||} = \frac{A^c - I(x)^c}{A^c - J(x)^c} \tag{3}$$

c = color channel index and c ϵ r, g, b

3. The scenic radiance is recovered by,

$$J(x) = \frac{I(x) - A}{max(t(x), t_0)} + A \tag{4}$$

4. **Obtaining Dark Channel**

$$J^{dark}(x) = min_{y \in \Omega(x)} \left(min_{c \in [r,g,b]} J^c(y) \right) \tag{5}$$

Where,
$J^c \longrightarrow$ Single color channel of image J
$\Omega(x) \longrightarrow$ x patch centered locally Thus, Dark channel is the result of applying two minimum operators.
If J being outdoor fog-free image, then the intensity of dark channel of J is nearly equal to zero.

$$J^{dark} \sim 0 \tag{6}$$

5. Calculating Boundary Constraint :
We assume that the scenic radiance J(x) of the image is always bounded from both sides,

$$C_0 \leq J(x) \leq C_1$$

C_0 and C_1 are two vectors having constant values related to the foogy image. Alower bound on value of t(x) is calculated resulting in following boundary provided constraint over t(x) as

$$0 \leq t_b(x) \leq t(x) \leq 1$$

Where $t_b(x)$ represents the lower bound on t(x) which is written as :

$$T^b(x) = min \left(max_{c \in [r,g,b]} \left(\frac{A^c - I^c(x)}{A^c - C_0^c}, \frac{A^c - I^c(x)}{A^c - C_1^c}, 1 \right) \right) \tag{7}$$

Using weighted function over constraints, the problem of getting halo artifacts when there is abrupt change in image depth can be solved.

$$W(m,n)(t(m) - t(n)) = 0 \tag{8}$$

Where,
m,n are neighbouring pixels. W(m,n) acts like a switch between constraints of m,n. When W(m,n) = 0 $\Rightarrow$ contextual constraints of t(x), of m,n is cancelled. Hence using color and intensity difference we give a weighting function as,

$$W(m,n) = e^{\frac{||I(m) - J(n)||^2}{2\rho^2}} \tag{9}$$

ρ is a prescribed parameter
Integrating weight function over whole image we get following contextual regulation on t(x):

$$\int_{m\in\Omega}^{\infty}\int_{y}^{\infty} W(m,n)|t(m)-y|dmdn \tag{10}$$

$$\sum_{i\in I}\sum_{j\in W_i} W_{ij}|t_i - t_j| \tag{11}$$

$$\sum_{j\in\omega} ||W_j.||D_j \circledast t|| \tag{12}$$

Where,
$\omega \Rightarrow$ index set
. $\Rightarrow$ element by element multiplication
$\circledast \Rightarrow$ convolution operator
$D_j \Rightarrow$ First order differential operator

6. Estimating the transmission map :
The method of estimation of transmission assumes that the transmission within a patch has constant value locally. We represent the transmission of patch as I(x). Applying minimum operator in local patch gives,

$$min_{y\in\Omega(x)}(I^c(y)) = t(x)min_{y\in\Omega(x)}(J^c(y)) + (1-t(x))A^c \tag{13}$$

The operator is applied on all channels independently. The estimated transmission map from a haze image is roughly good but it has some block effects since transmission is not always constant with in a patch.

1.6 Assumptions and Observations:

1. Global Airlight is assumed as maximum intensity of pixels in the image.
2. We assumed that transmission within a patch has constant value.
3. In a clear weather scattering coefficient tends to zero.
4. Attenuation decreases as the scene depth increases.
5. In order to find J(x) Fog free image from I(x) we need the values of A and t(x), at present it is not possible to estimate A and t(x) without prior assumptions.
6. For a fog-free image J^{dark} tends to zero.
7. We observed that the depth function for sky region tends to infinite.

8. As the assumption says the depth value is constant over the pixels in a patch, using this we derived a patch wise transmission map with the help of boundary constraints.
9. Weight function is inversely proportional to image depth.
10. Pixels having same intensity and color tend to be at same depth.

1.7 Challenges faced during the implementation:

- We have faced many errors while dealing with matrices.(dimensionality and type errors)
- Not knowing of how to use inbuilt functions(passing arguments)
- Learning syntax for MATLAB like,
    1. How to write functions
    2. How to use matrices (vectors)
    3. Loops
    4. Image related functions(filtering, color mapping, patching etc.,)
- Dealing with infinite looping etc.,
- While sub plotting the color map of all the images are changing, if we give color map for any one of the images.

We were able to sort out all of them with the help of seniors, documentation and internet.

1.8 Conclusion: We were able to gain knowledge on

1. In-depth study of used algorithms and techniques
2. Analysis of the most simple and effective technique that can be used for the pre-processing of the image.
3. Estimation Calculations for Transmission map and dark channel.
4. MATLAB implementation resulting in the depth map and dark channel of the fogged image
5. MATLAB implementation to recover the defogged image i.e. R, G, B components.

1.9 Output:

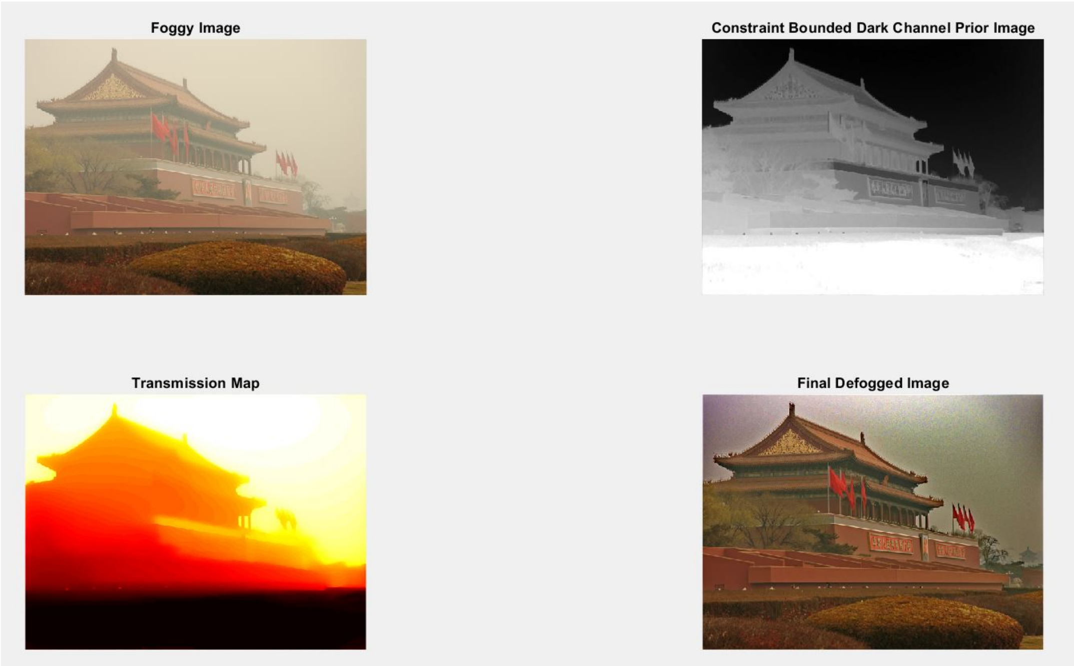

Figure 2: tiananmen.jpg

Figure 3: hongkong.jpg

Figure 4: forest.jpg

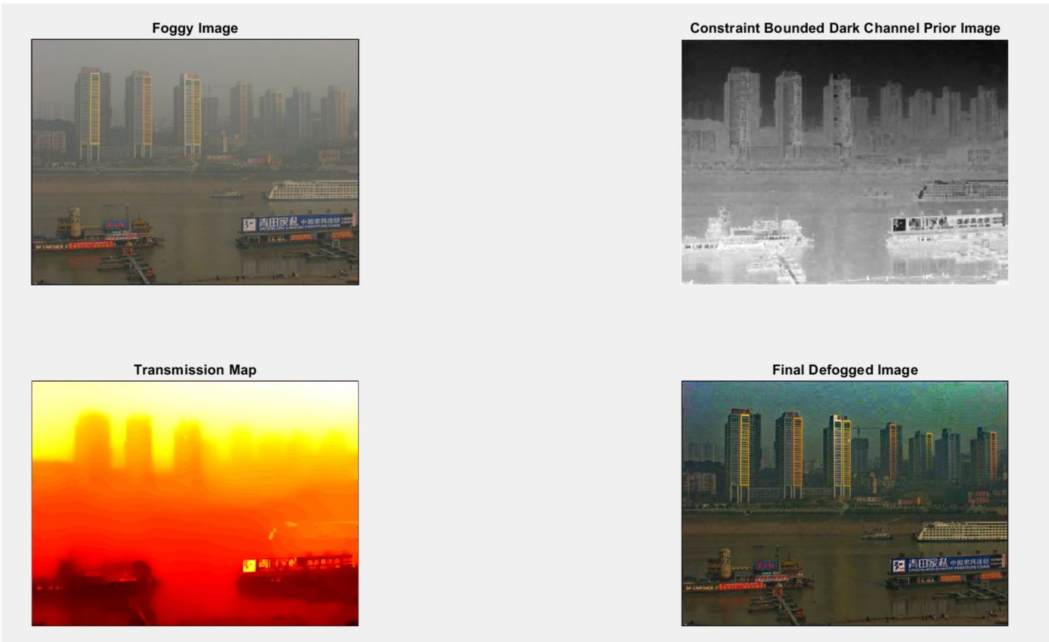

Figure 5: city.jpg

1.10 Limitations:

1. If the airlight(sky part) is more in the image then it tends to have bluish shade in the output.
2. The algorithm here is applied only for coloured images. It is invalid for gray scale images.
3. Because of fixed filter coefficients, we were unable to use it for wide range of foggy images.

1.11 Future Scope and Further research:

1. Looking forward to improve our algorithm to overcome the limitations.
2. Testing some post-processing techniques for enhancing the image contrast.(Local contrast enhancing and increasing the fine detail over the restored image to clearly observe the object in an image.)
3. Performance analysis is to be done and compare it with other methods.
4. Comparative Study Report is to be prepared.

1.12 Appendix:

Main Code

```
fogged = imread('unnamed.jpg'); %Fogged Image
figure, imshow(fogged);
%STEP.1. ESTIMATION OF GLOBAL AIRLIGHT.
frame = 10; % Local Patch Size
for k = 1 : 3
    minimum_intense = ordfilt2(double(fogged(:, :, k)), 25, ...
        ones(frame), 'symmetric');
    Airlight(k) = max(minimum_intense(:));
end
%STEP.2. CALCULATION OF DARK CHANNEL AND APPLY BOUNDARY CONSTRAINT
frame = 3;
bounded_fogged = boundary_constraint(fogged, Airlight, 30, 300, ...
    frame);
figure, imshow(bounded_fogged, []),title('Constraint Bounded ...
    Dark Channel Prior Image');
%STEP.3. TRANSMISSION MAP CALCULATION.
reg_param = 2;  % regularization parameter.
t = depth_map(fogged, bounded_fogged, reg_param, 0.5);
figure, imshow(1-t, []); colormap hot,title('Transmission Map');
%STEP.4. RECOVERY OF DE-FOGGED IMAGE.
defog_param = 0.85;
t = max(abs(t), 0.0001).^defog_param;
fogged = double(fogged);
if length(Airlight) == 1
    Airlight = Airlight * ones(3, 1);
end
R = (fogged(:, :, 1) - Airlight(1)) ./ t + Airlight(1);
G = (fogged(:, :, 2) - Airlight(2)) ./ t + Airlight(2);
B = (fogged(:, :, 3) - Airlight(3)) ./ t + Airlight(3);
defogged = cat(3, R, G, B) ./ 255;
figure, imshow(defogged, []),title('Final Defogged Image');
```

Boundary Constraint Function

```
function [p1, p2] = boundary_constraint(fogged, Airlight, C0, ...
    C1, frame)
% patch wise transmission from boundary constraint

if length(Airlight) == 1
    Airlight = Airlight * ones(3, 1);
end
```

```
if length(C0) == 1
    C0 = C0 * ones(3, 1);
end
if length(C1) == 1
    C1 = C1 * ones(3, 1);
end
fogged = double(fogged);

% pixel-wise boundary
t_r = max((Airlight(1) - fogged(:, :, 1)) ./ (Airlight(1)  -  ...
    C0(1)), (fogged(:, :, 1) - Airlight(1)) ./ (C1(1) - ...
    Airlight(1) ));
t_g = max((Airlight(2) - fogged(:, :, 2)) ./ (Airlight(2)  - ...
    C0(2)), (fogged(:, :, 2) - Airlight(2)) ./ (C1(2) - ...
    Airlight(2) ));
t_b = max((Airlight(3) - fogged(:, :, 3)) ./ (Airlight(3)  - ...
    C0(3)), (fogged(:, :, 3) - Airlight(3)) ./ (C1(3) - ...
    Airlight(3) ));
p2 = max(cat(3, t_r, t_g, t_b), [], 3);
p2 = min(p2, 1);

% minimum filtering
se = strel('square', frame);
p1 = imclose(p2, se);
```

Depth Map or Transmission Map

```
function bound_fogged = depth_map(fogged, bound_fogged, ...
    reg_param, val)

[nRows, nCols] = size(bound_fogged);

% various filters to be applied
nsz = 3; total = nsz * nsz;
d{1} = [5, 5, 5; -3, 0, -3; -3, -3, -3];
d{2} = [-3, 5, 5; -3, 0, 5; -3, -3, -3];
d{3} = [-3, -3, 5; -3, 0, 5; -3, -3, 5];
d{4} = [-3, -3, -3; -3, 0, 5; -3, 5, 5];
d{5} = [5, 5, 5; -3, 0, -3; -3, -3, -3];
d{6} = [-3, -3, -3; 5, 0, -3; 5, 5, -3];
d{7} = [5, -3, -3; 5, 0, -3; 5, -3, -3];
d{8} = [5, 5, -3; 5, 0, -3; -3, -3, -3];

% normalizing filters
num_filters = length(d);
for k = 1 : num_filters
    d{k} = d{k} / norm(d{k}(:));
```

```
end

% calculating weighting function
for k = 1 : num_filters
    weight{k} = weight_function(fogged, d{k}, val);
end

Tf = fft2(bound_fogged);
DS = 0;
for k = 1 : num_filters
    D{k} = psf2otf(d{k}, [nRows, nCols]);
    DS = DS + abs(D{k}).^2;
end

xponent = 1; xponent_rate = 2 * sqrt(2);
xponent_max = 2^8;

while xponent < xponent_max

    gamma = reg_param / xponent;

    DU = 0;
    for k = 1 : num_filters
        dt{k} = imfilter(bound_fogged, d{k}, 'circular');
        u{k} = max(abs(dt{k}) - weight{k} / xponent / ...
            num_filters, 0) .* sign(dt{k});
        DU = DU + fft2(imfilter(u{k}, flipud(fliplr(d{k})), ...
            'circular'));
    end

    bound_fogged = abs(ifft2((gamma * Tf + DU) ./ ( gamma + DS)));

    xponent = xponent * xponent_rate;
end

%%
function Weight = weight_function(fogged, D, val)
fogged = double(fogged) / 255;
d_r = imfilter(fogged(:, :, 1), D, 'circular');
d_g = imfilter(fogged(:, :, 2), D, 'circular');
d_b = imfilter(fogged(:, :, 3), D, 'circular');
Weight = exp(-(d_r.^2 + d_g.^2 + d_b.^2) / val / 2);
```

1.13 References:

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3. J.-P. Tarel and N. Hautiere, "Fast visibility restoration from a single color or gray level image," Proc. IEEE Int. Conf. on Computer Vision, pp. 2201–2208, Sep.–Oct. 2009.

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