COMP ENG 4TN4

Assignment 2
Homomorphic Filtering

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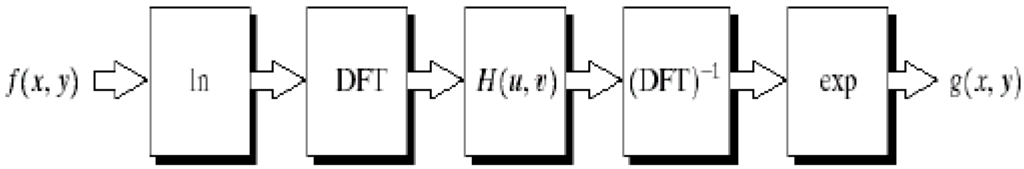
Homomorphic Filtering

Some images suffer from poor quality due to the non-uniform illumination in the image. Homomorphic filtering can be used to perform illumination correction by normalizing the brightness across the image. In homomorphic filtering, an image is nonlinearly mapped onto a different domain by taking the natural logarithm of the image. In this domain, linear high-pass filters are applied, and then the exponent is taken in order to map it back to the original image domain.



An image can be regarded as the product of illumination and reflectance, as shown in the following equation.

$$f(x, y) = i(x, y) \cdot r(x, y)$$

The equation cannot be used directly in order to operate separately on the frequency components of illumination and reflectance, because the Fourier transform of the product of two functions is not separable. Separation of the illumination and reflectance components can be done by taking the logarithm of the image, as shown in the following equations.

ln : $z(x,y) = \ln f(x,y) = \ln i(x,y) + \ln r(x,y)$

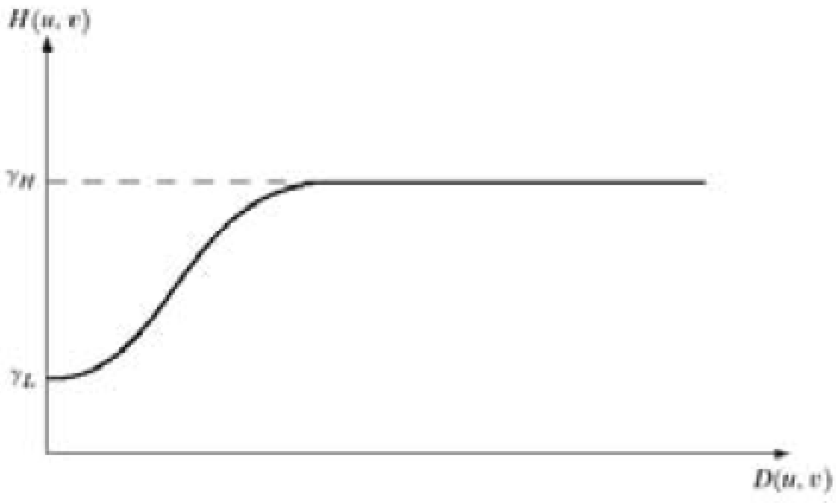
DFT : $Z(u,v) = F_i(u,v) + F_r(u,v)$

H(u,v) : $S(u,v) = H(u,v)Z(u,v)$

(DFT)$^{-1}$: $s(x,y) = i'(x,y) + r'(x,y)$

exp : $g(x,y) = e^{s(x,y)} = i_0(x,y) r_0(x,y)$

The illumination component of an image can be assumed to generally have slow variations, while the reflectance components may vary abruptly. These characteristics lead to associating the low frequencies of the Fourier transform of the logarithm of the image with illumination and the high frequencies with reflectance. By removing low frequencies through high-pass filtering function shown below, the effects of illumination can be removed.

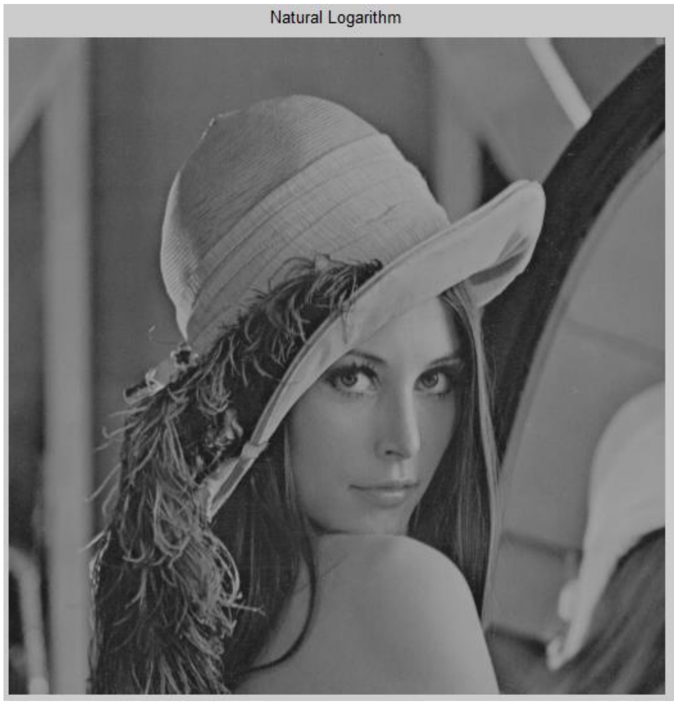


This figure shows the cross section of a secularly symmetric filter function where D(u,v) is the distance from the origin of the centered transform. The low frequency components are not fully attenuated, while the high frequency components are amplified.

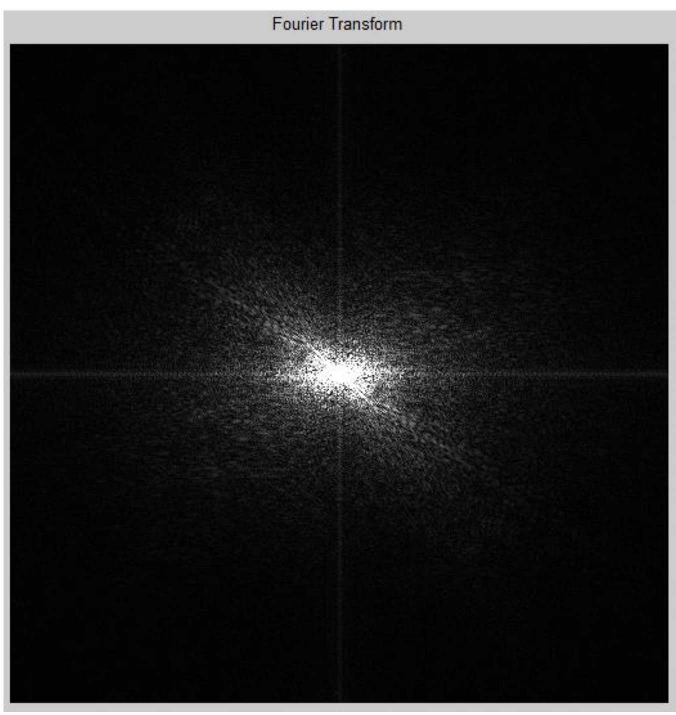
Implementation

The full implementation of the homomorphic filtering procedure is demonstrated on the following original image.

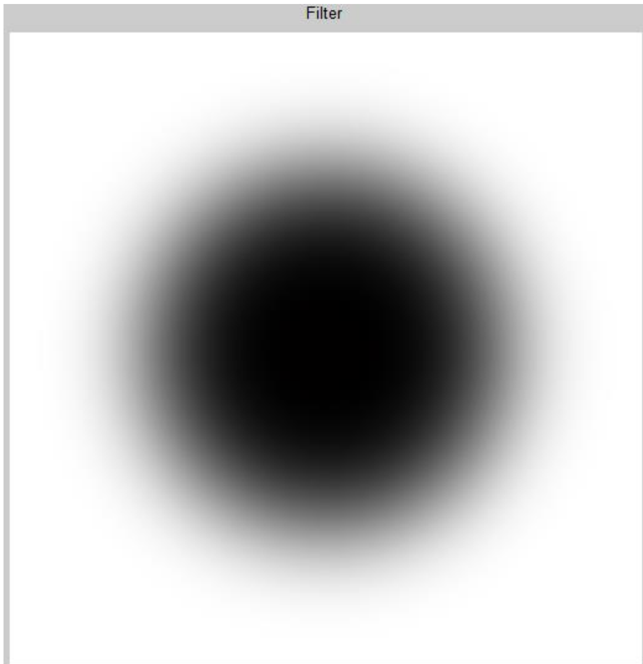
First, the logarithm of the image is taken as shown in the following figure. The image is clearly darker than the original image, as expected.



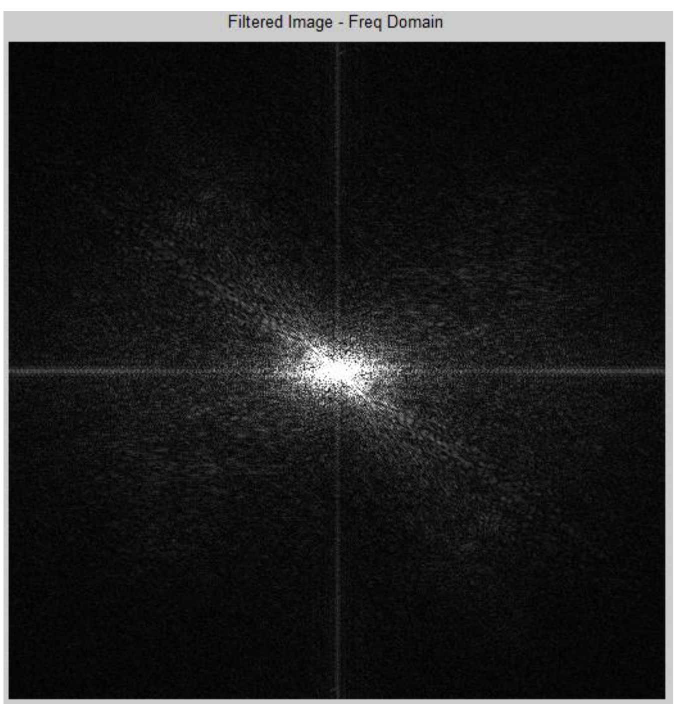
Next, the Fourier transform is applied on the logarithm of the image to transform it into the frequency domain.



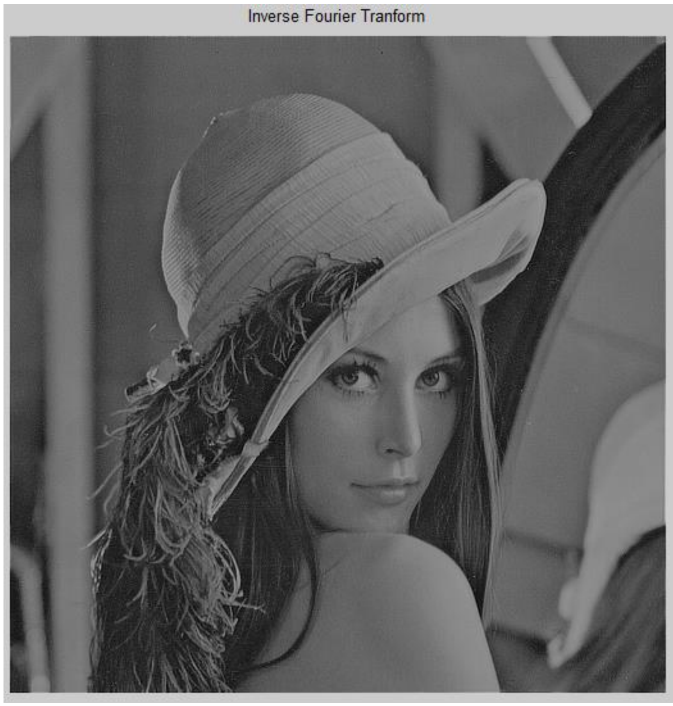
The filter used in the homomorphic filtering process is shown in the figure below. A Gaussian high-pass filter is used with a cutoff frequency of 128. The lower and upper bound of gamma used for this example is 0.9 and 2.5, respectively.



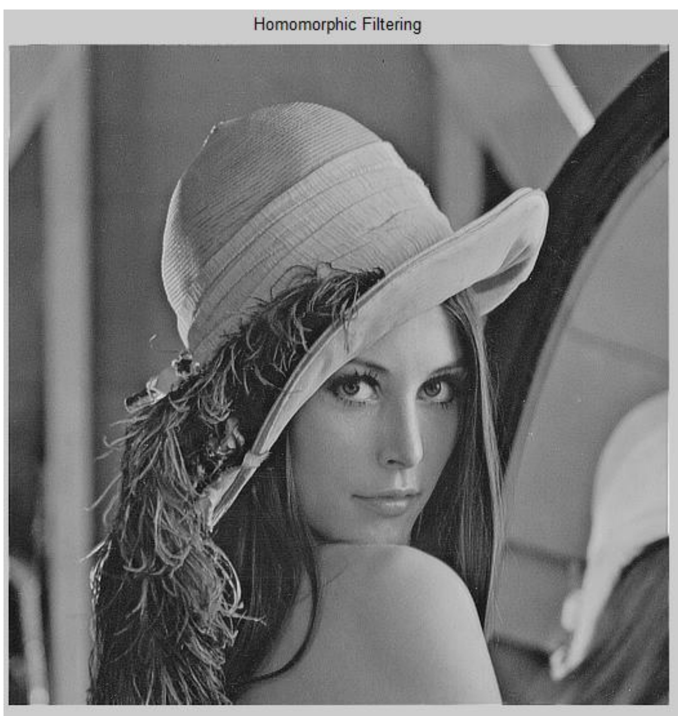
This filter is applied to the Fourier transform of the logarithm of the image by multiplying in the frequency domain to obtain the following figure. The values in the low frequency range have been attenuated while the high frequency components are boosted.



The inverse Fourier transform of the enhanced frequency domain image is taken to obtain the following image.

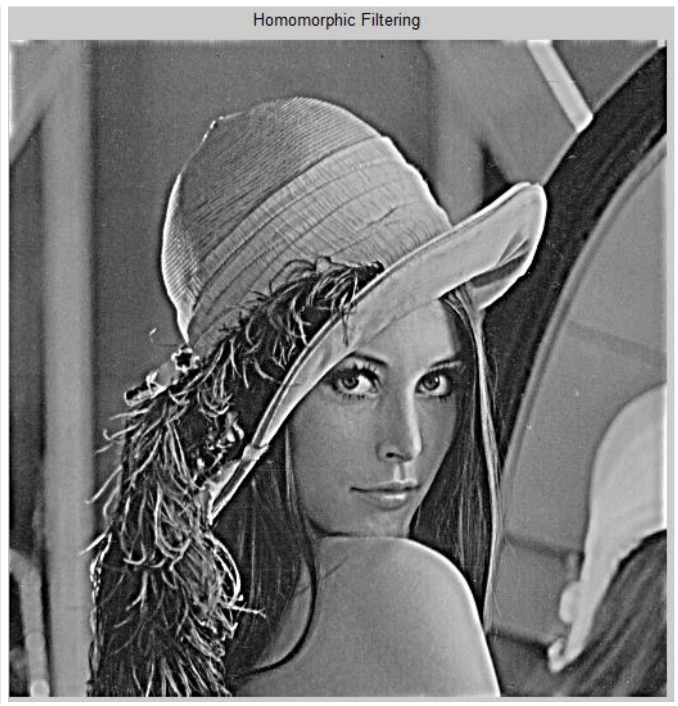


Finally, in order to transform the image back to its original domain, the exponent must be taken. This results in the final output shown below.

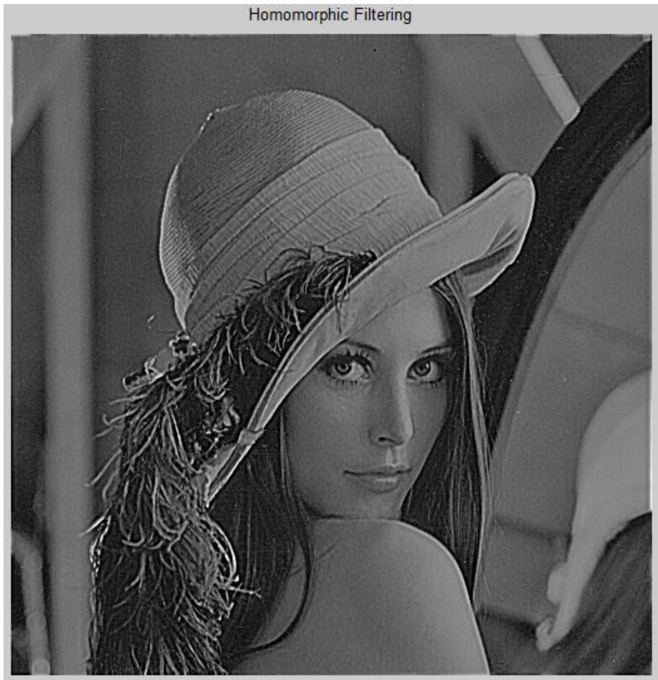


The goal of homomorphic filtering was to perform illumination correction, which was achieved as shown in the resulting image above. In areas of the skin, the original image seems to have uneven illumination; however, in the output image these areas generally have closer gray-level values. The details of the image are preserved, and perhaps enhanced, due to the fact that a high-pass filter was used.

The homomorphic filter generally has three parameters that can be changed; the upper and lower gamma values and the cutoff. Adjusting the cutoff frequency values produces the following images. The image on the left uses a cutoff of 64 and the image on the right uses a cutoff of 32. As the cutoff frequency decreases, more of the high frequency components are amplified, as seen by the exaggerated edges in the images below. Increasing the cutoff frequency produces images that appear to be similar to the original image with lower brightness (attenuation depends on the value of the lower bound of gamma).



The effect of adjusting the upper bound of gamma (gammaH) and lower bound of gamma (gammaL) are also examined in the following images. The image on the left decreases the lower bound by using gammaL = 0.7 and gammaH = 2.5. This results in a darker image since most of the features of the image are part of the lower frequency range that is attenuated. The image on the right increases the upper bound by using gammaL = 0.9 and gammaH = 4.5. This results in the detailed parts of the image becoming more prominent. This may also lead to a grainy photo since noise generally consists of higher frequencies. In these images the cutoff was 64 Hz, and the results of adjusting gamma varies with different cutoff frequencies.



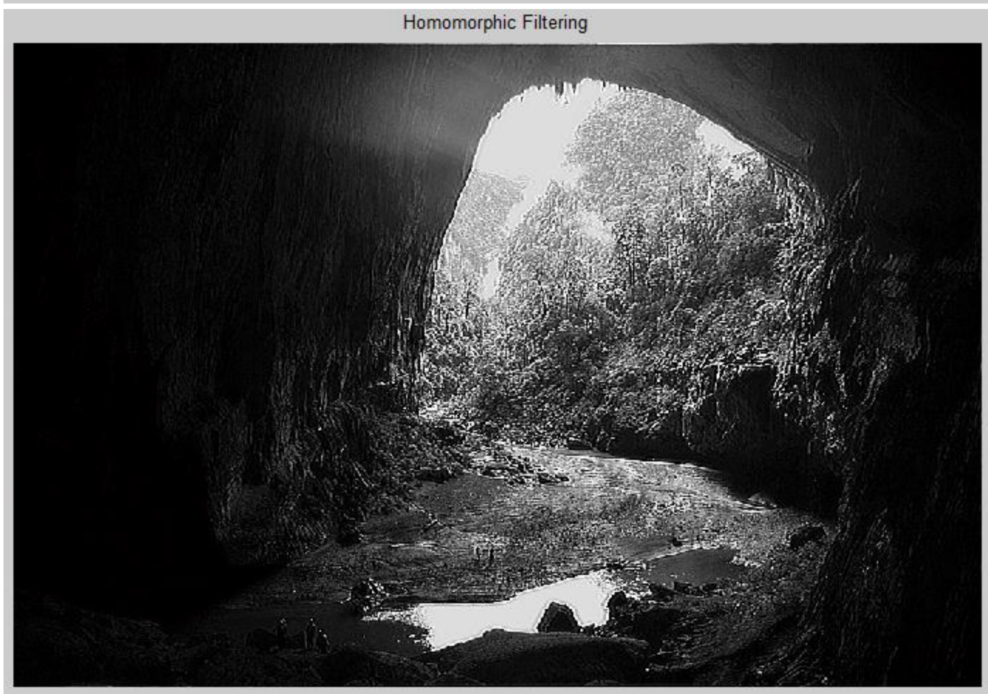
Examples

Further examples are examined for the homomorphic filter. In these examples, suitable values of the parameters were chosen for the particular image in order to achieve desirable results.

In the following example, the values of the parameters were cutoff = 128, gammaL = 1.5, and gammaH = 5.5. While the value of the lower bound of gamma is usually set below 1, in this example it was set higher than one due to the fact that the original image is generally very dark. The difference between the gamma values is still large and the details of the image are enhanced. In the final image the details of the face of girl in the foreground are more apparent and can be considered to have higher contrast in this area.

In the following example, the parameters are chosen as cutoff = 128, gammaL = 0.9, and gammaH = 4.1. The filtered image clearly shows more details than the original, especially apparent in the brick detailing of the buildings. However, the bright areas in the background have become darker than the original. The brightness of the background and the contrast between the sky and building in the background can be retained by using a gammaL of 1.

In the following example, the parameters were cutoff = 128, gammaL = 0.9, and gammaH = 5.5. By having a high difference in gamma, more of the details on the inside of the cave are visible. The uneven illumination between the inside and outside of the cave is corrected.



Matlab Code:

```
% 4TN4 Assignment 2
% Homomorphic filter
clear all; close all; clc;

% img = imread('lena.png');
% img = imread('street_orig.png');
% img = imread('girl_orig.png');
img = imread('cave.jpg');
imsize = size(img);
if (numel(imsize)>2)
    img = rgb2gray(img);
end

figure(1)
imshow(img);
title('Original Image');

cimg = im2double(img);
%add 1 to pixels to remove 0 values resulting in undefined log values
cimg = cimg + 1;

% Natural logarithm
limg = log(cimg);
% figure(3)
% imshow(limg);
% title('Natural Logarithm');

% Fourier Transform
fimg = fft2(limg);
% figure(4)
% imshow(uint8(abs(fftshift(fimg))));
% title('Fourier Transform');

% Gaussian High-Pass Filter
D0 = 128;    %cutoff frequency
D0 = D0^2;
[M,N,P] = size(img);
u = 0:(M-1);    %set up range of variables
v = 0:(N-1);

idx = find(u>(M/2));    %compute indices for meshgrid
idy = find(v>(N/2));
u(idx) = u(idx) - M;
v(idy) = v(idy) - N;

%meshgrid frequency matrices for computing freq domain filters
[U, V] = meshgrid(u,v);

D = U.^2 + V.^2;    %compute distances to center of filter

gaussH = 1 - (exp(-(D.^2)./(2*(D0^2)))); %gaussian lowpass filter

% Homomorphic Filter
```

```
gammaL = 0.9;
gammaH = 5.5;
diff = gammaH - gammaL;

gaussH = diff*gaussH + gammaL;
% figure(5)
% imshow(mat2gray(fftshift(gaussH)));
% title('Filter');

himg = gaussH'.*fimg;
% figure(6)
% imshow(uint8(abs(fftshift(himg))));
% title('Filtered Image - Freq Domain');

% Inverse Fourier Transform
ifimg = ifft2(himg);
% figure(7)
% imshow(ifimg);
% title('Inverse Fourier Tranform');

% Exponent
eimg = exp(ifimg) - 1;

figure(2)
imshow(eimg);
title('Homomorphic Filtering');
```