IMAGE DEHAZING USING STEERING KERNEL WEIGHTED GUIDED IMAGE FILTERING

PROJECT DESCRIPTION

We have implemented the research paper Weighted Guided Image Filtering with Steering Kernel (attached in the folder) and merged it with 3 other research papers, namely Guided Image Filtering, Kernel Regression and Single Haze Removal for the purpose of application in Image Dehazing and Enhancement using SKWGIF.

We have divided the project into three parts namely:

1. Steering Kernel WGIF Implementation
2. Image Dehazing Using SKWGIF and Histogram Equalization
3. Coloured Image Dehazing Using SKWGIF

- **Steering Kernel WGIF Implementation**

We have implemented WGIF with a Steering Kernel (SKWGIF). GIF and WGIF suffers from Halo Artifacts. SKWGIF takes advantage of WGIF over GIF while leveraging the edge direction more sufficiently. The code uses Steering Kernel which in turn requires local gradient matrices. The steering kernel helps us to identify the energy dominant directions. We have used different values for the radius of the local window and the regularization parameter. The comparison results clearly show the advantage of using SKWGIF over WGIF and GIF.

Code

```
import cv2
import numpy as np
from math import *

def Grad_func(img):
    '''
    This Function returns Local Gradient Matrices.
    Parameters
    ----------
    img : Image
        Input Image for which Local Gradient Matrices are to be found.

    Returns
    -------
    Grad_mat : 2D Numpy Matrix
            Matrix containing Local Gradient Matrix for every pixel in input image.
    '''
    dummy_mat = np.array([[0.00 for j in range(2)] for i in range(9)])
```

```
    Grad_mat = [[dummy_mat for j in range(img.shape[1])] for i in range(img.shape[0])]
    for i in range(1, img.shape[0]-1):
        for j in range(1, img.shape[1]-1):
            Gij = []
            roi = img[i-1:i+2, j-1:j+2]
            gx = cv2.Sobel(roi,cv2.CV_64F, 1, 0, ksize = 1)
            gy = cv2.Sobel(roi, cv2.CV_64F, 0, 1, ksize = 1)
            gx = np.reshape(gx,(9, ))
            gy = np.reshape(gy,(9, ))
            Gij.append(gx)
            Gij.append(gy)
            Grad_mat[i][j] = np.transpose(Gij)
    return Grad_mat

def steering_kernel(img):
    '''
    This Function Returns Steering Kernel Matrices.
    Parameters
    ----------
    img : Image

    Returns
    -------
    W : 2D Numpy Matrix
        Matrix containing Steering Kernel Weight Matrices for each pixel in input image.
    '''
    Grad_mat = Grad_func(img*255)
    dummy_mat = np.array([[0 for j in range(3)] for i in range(3)])
    W = [[dummy_mat for j in range(img.shape[1])] for i in range(img.shape[0])]
    for i in range(1, img.shape[0]-1):
        for j in range(1, img.shape[1]-1):
            u, s, v = np.linalg.svd(Grad_mat[i][j])
            v2 = v[1]
            if v2[1] == 0:
                theta = pi/2
            else:
                theta = np.arctan(v2[0]/v2[1])
            sigma = (s[0] + 1.0)/(s[1] + 1.0)
            gamma = sqrt(((s[0]*s[1]) + 0.01)/9)
            Rot_mat = np.array([[cos(theta), sin(theta)], [-(sin(theta)), cos(theta)]])
            El_mat = np.array([[sigma, 0], [0, (1/sigma)]])
            C = gamma*(np.dot(np.dot(Rot_mat, El_mat), np.transpose(Rot_mat)))
            coeff = sqrt(np.linalg.det(C))/(2*pi*(5.76))
            W_i = [[0 for q in range(3)] for p in range(3)]
            for n_i in range(i-1, i+2):
                for n_j in range(j-1, j+2):
                    xi = np.array([i, j])
                    xk = np.array([n_i, n_j])
```

```
            xik = xi - xk
            wik = coeff*(exp(-(np.dot(np.dot(np.transpose(xik), C), xik))/(11.52)))
            W_i[n_i-i+1][n_j-j+1] = wik
        W[i][j] = W_i
    return W

def Guided_Image_Filter(im,p,r,eps):
    '''
    This Function returns the output for
    Guided Image Filter applied on Input Image.
    Parameters
    ----------
    im : Guidance Image

    p : Input Filter Image

    r : Radius of Kernel

    eps : Regularization parameter

    Returns
    -------
    q : Output Image after GIF application
    '''
    mean_I = cv2.boxFilter(im,cv2.CV_64F,(r,r))
    mean_p = cv2.boxFilter(p, cv2.CV_64F,(r,r))
    mean_Ip = cv2.boxFilter(im*p,cv2.CV_64F,(r,r))
    cov_Ip = mean_Ip - mean_I*mean_p

    mean_II = cv2.boxFilter(im*im,cv2.CV_64F,(r,r))
    var_I   = mean_II - mean_I*mean_I

    a = cov_Ip/(var_I + eps)
    b = mean_p - a*mean_I

    mean_a = cv2.boxFilter(a,cv2.CV_64F,(r,r))
    mean_b = cv2.boxFilter(b,cv2.CV_64F,(r,r))
    cv2.imshow("Edge_GIF", mean_a)
    q = mean_a*im + mean_b
    return q

def Weighted_Guided_Image_Filter(im, p, r, r2, eps, lamda, N):
    '''
    This Function returns the output for Weighted
    Guided Image Filter applied on Input Image.
    Parameters
    ----------
    im : Guidance Image
```

```python
    p : Input Filter Image

    r : Radius of Kernel

    r2 : Radius of Local Window centered at a particular pixel

    eps : Regularization parameter

    lamda : small constant dependent on dynamic range

    N : Number of Pixels in the Input image

    Returns
    -------
    q : Output Image after WGIF application
    '''
    mean_I = cv2.boxFilter(im,cv2.CV_64F,(r,r))
    mean_I2  = cv2.boxFilter(im, cv2.CV_64F,(r2,r2))
    mean_p = cv2.boxFilter(p, cv2.CV_64F,(r,r))
    mean_p2 = cv2.boxFilter(p, cv2.CV_64F, (r2,r2))

    corr_I = cv2.boxFilter(im*im, cv2.CV_64F,(r,r))
    corr_I2 = cv2.boxFilter(im*im,cv2.CV_64F,(r2,r2))
    corr_Ip = cv2.boxFilter(im*p,cv2.CV_64F,(r,r))

    var_I = corr_I - mean_I*mean_I
    var_I2 = corr_I2 - mean_I2*mean_I2

    PsiI = ((var_I2+lamda)*np.sum(1/(var_I2 + lamda)))/N
    cov_Ip = corr_Ip - mean_I*mean_p

    a_psi = cov_Ip/(var_I + eps/PsiI)
    b_psi = mean_p - (a_psi)*mean_I
    mean_ap = cv2.boxFilter(a_psi,cv2.CV_64F,(r2,r2))
    mean_bp = cv2.boxFilter(b_psi,cv2.CV_64F,(r2,r2))
    cv2.imshow("Edge_WGIF", mean_ap)
    qp = mean_ap*im + mean_bp
    return qp

def SK_Weighted_Guided_Image_Filter(im,p,r,r2,eps,lamda,N):
    '''
    This Function returns the output for Steering Kernel
    Weighted Guided Image Filter applied on Input Image.
    Parameters
    ----------
    im : Guidance Image
```

p : Input Filter Image

r : Radius of Kernel

r2 : Radius of Local Window centered at a particular pixel

eps : Regularization parameter

lamda : small constant dependent on dynamic range

N : Number of Pixels in the Input image

Returns
----
q : Output Image after SKWGIF application
'''

```
mean_I = cv2.boxFilter(im,cv2.CV_64F,(r,r))
mean_I2  = cv2.boxFilter(im, cv2.CV_64F,(r2,r2))
mean_p = cv2.boxFilter(p, cv2.CV_64F,(r,r))
mean_p2 = cv2.boxFilter(p, cv2.CV_64F, (r2,r2))

corr_I = cv2.boxFilter(im*im, cv2.CV_64F,(r,r))
corr_I2 = cv2.boxFilter(im*im,cv2.CV_64F,(r2,r2))
corr_Ip = cv2.boxFilter(im*p,cv2.CV_64F,(r,r))

var_I = corr_I - mean_I*mean_I
var_I2 = corr_I2 - mean_I2*mean_I2

PsiI = ((var_I2+lamda)*np.sum(1/(var_I2 + lamda)))/N

cov_Ip = corr_Ip - mean_I*mean_p

a_psi = cov_Ip/(var_I + eps/PsiI)
b_psi = mean_p - (a_psi)*mean_I

W = steering_kernel(im)

mean_a = [[0 for j in range(im.shape[1])] for i in range(im.shape[0])]
mean_b = [[0 for j in range(im.shape[1])] for i in range(im.shape[0])]

for i in range(1, im.shape[0]-1):
   for j in range(1, im.shape[1]-1):
      Wk = W[i][j]
      roi_a = a_psi[i-1:i+2, j-1:j+2]
      roi_b = b_psi[i-1:i+2, j-1:j+2]
      mean_a[i][j] = np.sum(Wk*roi_a)
      mean_b[i][j] = np.sum(Wk*roi_b)
mean_a = np.array(mean_a)
```

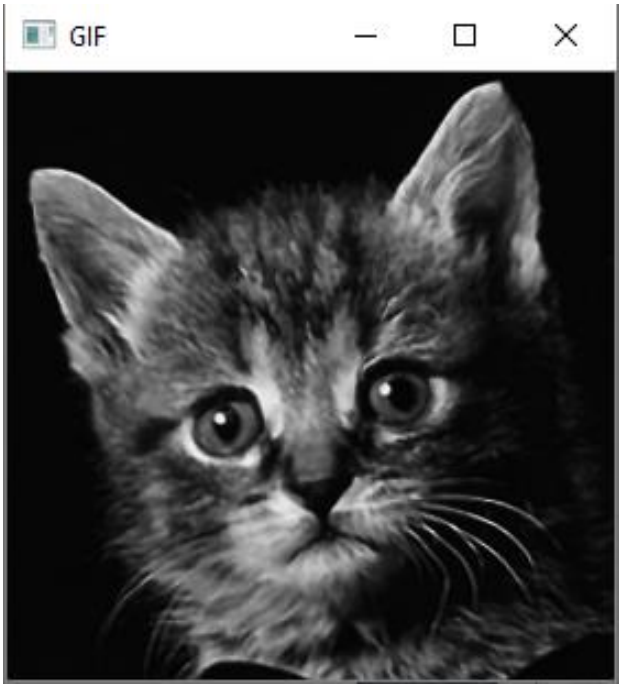
```python
    mean_b = np.array(mean_b)
    mean_b = b_psi
    cv2.imshow("Edge_SKWGIF", mean_a)
    q = mean_a*im + mean_b
    return q

def TransmissionRefine(im, et, r, eps, lamda, N):
    '''
    Parameters
    ----------
    im : Guidance Image

    et : Input Filter Image

    r : Radius of kernel

    eps : Regularization Parameter

    lamda : small constant dependent on dynamic range

    N : Number of Pixels in the Input image

    Returns
    -------
    None.
    '''
    gray = np.float64(im)/255
    rd = 3
    GIF = Guided_Image_Filter(gray, gray, r, eps)
    WGIF = Weighted_Guided_Image_Filter(gray, gray, r, rd, eps, lamda, N)
    SKWGIF = SK_Weighted_Guided_Image_Filter(gray, gray, r, rd, eps, lamda, N)
    cv2.imshow("GIF", GIF)
    cv2.imshow("WGIF", WGIF)
    cv2.imshow("SKWGIF", SKWGIF)

src = cv2.imread("cat.png")
gray = cv2.cvtColor(src, cv2.COLOR_BGR2GRAY)
cv2.imshow("gray image", gray)
minimum = np.min(gray)
maximum = np.max(gray)
L = (maximum-minimum)
lamda = (0.001*L)**2
rows, columns = gray.shape
N = rows*columns
r = [2, 4, 8]
eps = [0.01, 0.04, 0.16]
TransmissionRefine(gray, gray, r[0], eps[0], lamda, N)
```

RESULTS AND COMPARISON:

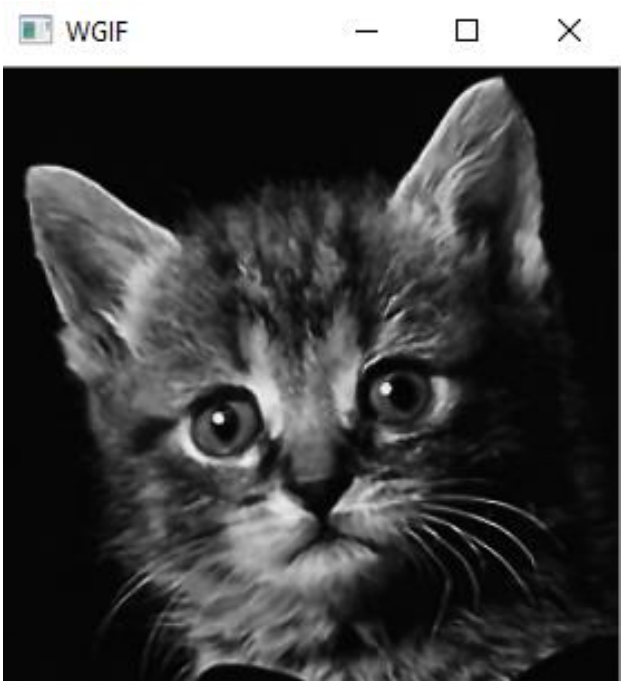
COMPARISON 1:

ORIGINAL IMAGE

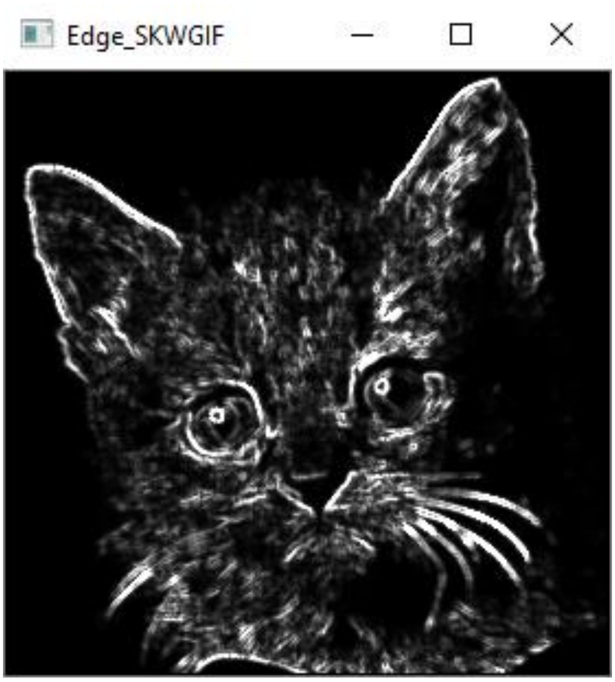
GIF FILTERING OUTPUT



WGIF FILTERING OUTPUT



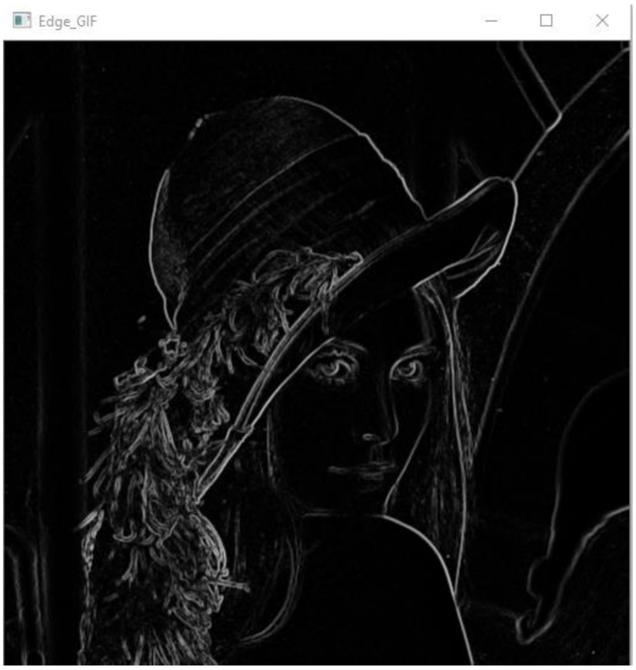
SKWGIF FILTERING OUTPUT



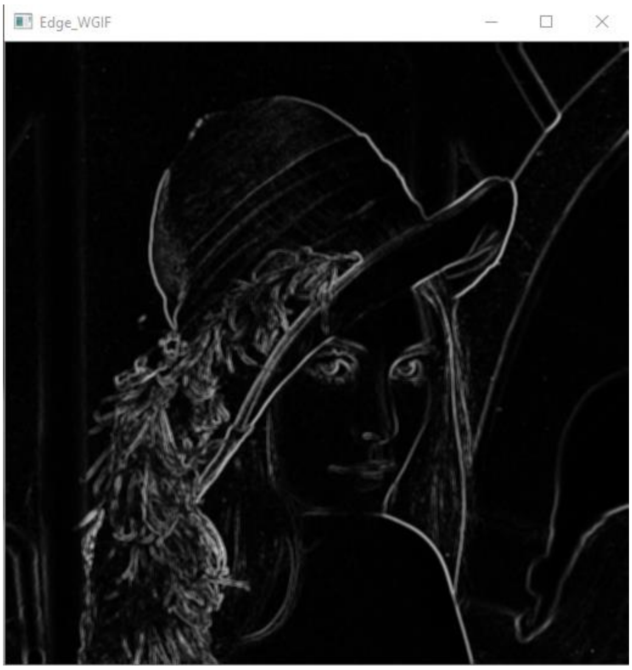
COMPARISON 2:

ORIGINAL IMAGE

GIF FILTERING OUTPUT



WGIF FILTERING OUTPUT



SKWGIF FILTERING OUTPUT

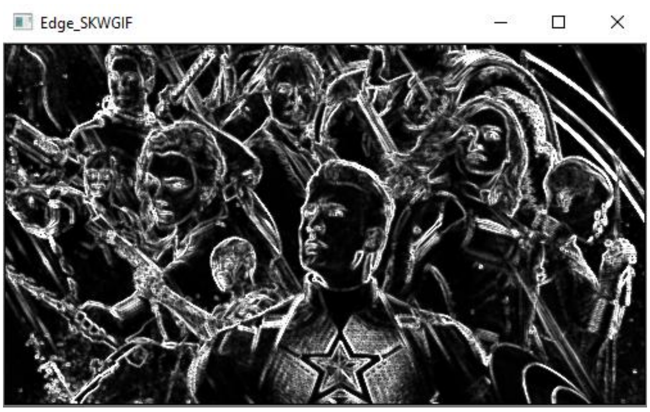
COMPARISON 3:

ORIGINAL IMAGE

GIF FILTERING OUTPUT

WGIF FILTERING OUTPUT

SKWGIF FILTERING OUTPUT



- **Image Dehazing Using SKWGIF and Histogram Equalization**

We have implemented Image Dehazing for Grayscale Images. First, we applied Histogram Equalization to increase the dynamic range of the image. Then we have used SKWGIF for detail enhancement and edge retention which reduces the contrast of background noise. The Code uses Histogram Equalization function followed by SKWGIF function. The results are presented by varying the values for radius of local window and regularization parameter. SKWGIF gives better results than GIF and WGIF due to supreme edge detection.

Code

```
import cv2
import cv2
import numpy as np
from math import *

#Histogram equalisation
def Histogram_Eq(resized_image):
    """
    This Function returns Histogram Equalised Image for Contrast Enhancement.

    Parameters
    ----------
    resized_image : Input Image

    Returns
    -------
    resized_image : Histogram Equalized Image
    """
    r = []
    no_of_pixel = (resized_image.shape[0] * resized_image.shape[1])
    r = np.ravel(resized_image)
    unique, count = np.unique(r, return_counts=True)
    #print(unique)
    counts = np.zeros((256, ))
    val = 0
    for i in range(256):
        if i in unique:
            counts[i] = count[val]
            val += 1;

    sigma_list = []
    sigma_list.append(counts[0])
    for i in range(1, 256):
        cnt = counts[i]
```

```
        sigma_list.append(sigma_list[i - 1] + cnt)

    sigma_list = np.array(sigma_list)
    final_list = (sigma_list*255)/(no_of_pixel)#[(x*255)/(no_of_pixel) for x in sigma_list]
    for i in range(resized_image.shape[0]):
        for j in range(resized_image.shape[1]):
            temp = resized_image[i][j]
            resized_image[i][j] = final_list[temp]
    return resized_image

def Grad_func(img):
    '''
    This Function returns Local Gradient Matrices.
    Parameters
    ----------
    img : Image
        Input Image for which Local Gradient Matrices are to be found.

    Returns
    -------
    Grad_mat : 2D Numpy Matrix
            Matrix containing Local Gradient Matrix for every pixel in input image.
    '''
    dummy_mat = np.array([[0.00 for j in range(2)] for i in range(9)])
    Grad_mat = [[dummy_mat for j in range(img.shape[1])] for i in range(img.shape[0])]
    for i in range(1, img.shape[0]-1):
        for j in range(1, img.shape[1]-1):
            Gij = []
            roi = img[i-1:i+2, j-1:j+2]
            gx = cv2.Sobel(roi,cv2.CV_64F, 1, 0, ksize = 1)
            gy = cv2.Sobel(roi, cv2.CV_64F, 0, 1, ksize = 1)
            gx = np.reshape(gx,(9, ))
            gy = np.reshape(gy,(9, ))
            Gij.append(gx)
            Gij.append(gy)
            Grad_mat[i][j] = np.transpose(Gij)
    return Grad_mat

def steering_kernel(img):
    '''
    This Function Returns Steering Kernel Matrices.
    Parameters
    ----------
    img : Image

    Returns
    -------
    W : 2D Numpy Matrix
```

```
    Matrix containing Steering Kernel Weight Matrices for each pixel in input image.
  '''
  Grad_mat = Grad_func(img*255)
  dummy_mat = np.array([[0 for j in range(3)] for i in range(3)])
  W = [[dummy_mat for j in range(img.shape[1])] for i in range(img.shape[0])]
  for i in range(1, img.shape[0]-1):
    for j in range(1, img.shape[1]-1):
      u, s, v = np.linalg.svd(Grad_mat[i][j])
      v2 = v[1]
      if v2[1] == 0:
        theta = pi/2
      else:
        theta = np.arctan(v2[0]/v2[1])
      sigma = (s[0] + 1.0)/(s[1] + 1.0)
      gamma = sqrt(((s[0]*s[1]) + 0.01)/9)
      Rot_mat = np.array([[cos(theta), sin(theta)], [-(sin(theta)), cos(theta)]])
      El_mat = np.array([[sigma, 0], [0, (1/sigma)]])
      C = gamma*(np.dot(np.dot(Rot_mat, El_mat), np.transpose(Rot_mat)))
      coeff = sqrt(np.linalg.det(C))/(2*pi*(5.76))
      W_i = [[0 for q in range(3)] for p in range(3)]
      for n_i in range(i-1, i+2):
        for n_j in range(j-1, j+2):
          xi = np.array([i, j])
          xk = np.array([n_i, n_j])
          xik = xi - xk
          wik = coeff*(exp(-(np.dot(np.dot(np.transpose(xik), C), xik))/(11.52)))
          W_i[n_i-i+1][n_j-j+1] = wik
      W[i][j] = W_i
  return W

def Guided_Image_Filter(im,p,r,eps):
  '''
  This Function returns the output for
  Guided Image Filter applied on Input Image.

  Parameters
  ----------
  im : Guidance Image

  p : Input Filter Image

  r : Radius of Kernel

  eps : Regularization parameter

  Returns
  -------
  q : Output Image after GIF application
```

```
    '''
    mean_I = cv2.boxFilter(im,cv2.CV_64F,(r,r))
    mean_p = cv2.boxFilter(p, cv2.CV_64F,(r,r))
    mean_Ip = cv2.boxFilter(im*p,cv2.CV_64F,(r,r))
    cov_Ip = mean_Ip - mean_I*mean_p

    mean_II = cv2.boxFilter(im*im,cv2.CV_64F,(r,r))
    var_I   = mean_II - mean_I*mean_I

    a = cov_Ip/(var_I + eps)
    b = mean_p - a*mean_I

    mean_a = cv2.boxFilter(a,cv2.CV_64F,(r,r))
    mean_b = cv2.boxFilter(b,cv2.CV_64F,(r,r))
    cv2.imshow("Edge_GIF", mean_a)
    q = mean_a*im + mean_b
    return q

def Weighted_Guided_Image_Filter(im, p, r, r2, eps, lamda, N):
    '''
    This Function returns the output for Weighted
    Guided Image Filter applied on Input Image.

    Parameters
    ----------
    im : Guidance Image

    p : Input Filter Image

    r : Radius of Kernel

    r2 : Radius of Local Window centered at a particular pixel

    eps : Regularization parameter

    lamda : small constant dependent on dynamic range

    N : Number of Pixels in the Input image

    Returns
    -------
    q : Output Image after WGIF application
    '''
    mean_I = cv2.boxFilter(im,cv2.CV_64F,(r,r))
    mean_I2  = cv2.boxFilter(im, cv2.CV_64F,(r2,r2))
    mean_p = cv2.boxFilter(p, cv2.CV_64F,(r,r))
    mean_p2 = cv2.boxFilter(p, cv2.CV_64F, (r2,r2))
```

```
    corr_I = cv2.boxFilter(im*im, cv2.CV_64F,(r,r))
    corr_I2 = cv2.boxFilter(im*im,cv2.CV_64F,(r2,r2))
    corr_Ip = cv2.boxFilter(im*p,cv2.CV_64F,(r,r))

    var_I = corr_I - mean_I*mean_I
    var_I2 = corr_I2 - mean_I2*mean_I2

    PsiI = ((var_I2+lamda)*np.sum(1/(var_I2 + lamda)))/N

    cov_Ip = corr_Ip - mean_I*mean_p

    a_psi = cov_Ip/(var_I + eps/PsiI)
    b_psi = mean_p - (a_psi)*mean_I
    mean_ap = cv2.boxFilter(a_psi,cv2.CV_64F,(r2,r2))
    mean_bp = cv2.boxFilter(b_psi,cv2.CV_64F,(r2,r2))
    cv2.imshow("Edge_WGIF", mean_ap)
    qp = mean_ap*im + mean_bp
    return qp


def SK_Weighted_Guided_Image_Filter(im,p,r,r2,eps,lamda,N):
    '''
    This Function returns the output for Steering Kernel
    Weighted Guided Image Filter applied on Input Image.

    Parameters
    ----------
    im : Guidance Image

    p : Input Filter Image

    r : Radius of Kernel

    r2 : Radius of Local Window centered at a particular pixel

    eps : Regularization parameter

    lamda : small constant dependent on dynamic range

    N : Number of Pixels in the Input image

    Returns
    -------
    q : Output Image after SKWGIF application
    '''
    mean_I = cv2.boxFilter(im,cv2.CV_64F,(r,r))
    mean_I2  = cv2.boxFilter(im, cv2.CV_64F,(r2,r2))
    mean_p = cv2.boxFilter(p, cv2.CV_64F,(r,r))
```

```
    mean_p2 = cv2.boxFilter(p, cv2.CV_64F, (r2,r2))

    corr_I = cv2.boxFilter(im*im, cv2.CV_64F,(r,r))
    corr_I2 = cv2.boxFilter(im*im,cv2.CV_64F,(r2,r2))
    corr_Ip = cv2.boxFilter(im*p,cv2.CV_64F,(r,r))

    var_I = corr_I - mean_I*mean_I
    var_I2 = corr_I2 - mean_I2*mean_I2

    PsiI = ((var_I2+lamda)*np.sum(1/(var_I2 + lamda)))/N

    cov_Ip = corr_Ip - mean_I*mean_p

    a_psi = cov_Ip/(var_I + eps/PsiI)
    b_psi = mean_p - (a_psi)*mean_I
    W = steering_kernel(im)

    mean_a = [[0 for j in range(im.shape[1])] for i in range(im.shape[0])]
    mean_b = [[0 for j in range(im.shape[1])] for i in range(im.shape[0])]

    for i in range(1, im.shape[0]-1):
        for j in range(1, im.shape[1]-1):
            Wk = W[i][j]
            roi_a = a_psi[i-1:i+2, j-1:j+2]
            roi_b = b_psi[i-1:i+2, j-1:j+2]
            mean_a[i][j] = np.sum(Wk*roi_a)
            mean_b[i][j] = np.sum(Wk*roi_b)
    mean_a = np.array(mean_a)
    mean_b = np.array(mean_b)
    mean_b = b_psi
    cv2.imshow("Edge_SKWGIF", mean_a)
    q = mean_a*im + mean_b
    return q

def TransmissionRefine(im, et, r, eps, lamda, N):
    '''
    Parameters
    ----------
    im : Guidance Image

    et : Input Filter Image

    r : Radius of kernel

    eps : Regularization Parameter

    lamda : small constant dependent on dynamic range
```

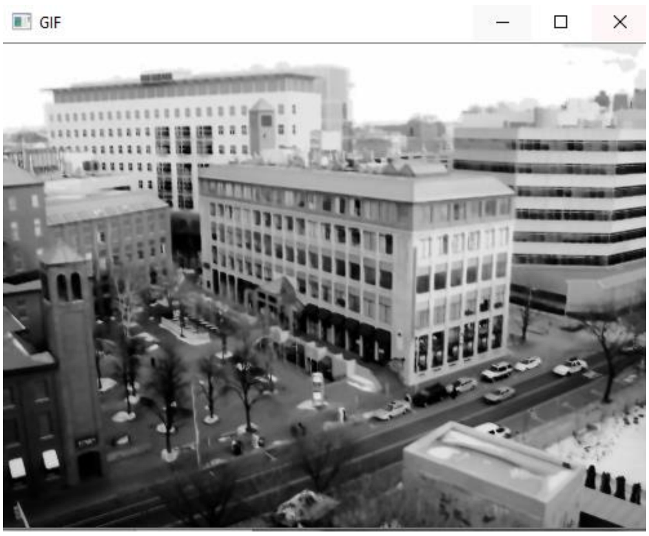
```
    N : Number of Pixels in the Input image

    Returns
    -------
    None.
    '''
    gray = np.float64(im)/255
    rd = 3
    GIF = Guided_Image_Filter(gray, gray, r, eps)
    WGIF = Weighted_Guided_Image_Filter(gray, gray, r, rd, eps, lamda, N)
    SKWGIF = SK_Weighted_Guided_Image_Filter(gray, gray, r, rd, eps, lamda, N)
    cv2.imshow("GIF", GIF)
    cv2.imshow("WGIF", WGIF)
    cv2.imshow("SKWGIF", SKWGIF)

original_image = cv2.imread('Input Images Used\Building with Haze.png', cv2.IMREAD_GRAYSCALE)
cv2.imshow("original_image", original_image)

histogram_equalised_image = Histogram_Eq(original_image)

gray = histogram_equalised_image

minimum = np.min(gray)
maximum = np.max(gray)
L = (maximum-minimum)
lamda = (0.001*L)**2
rows, columns = gray.shape
N = rows*columns
r = 2
eps = 0.01
TransmissionRefine(gray, gray, r, eps, lamda, N)
```

RESULT AND ANALYSIS

COMPARISON 1:

ORIGINAL IMAGE

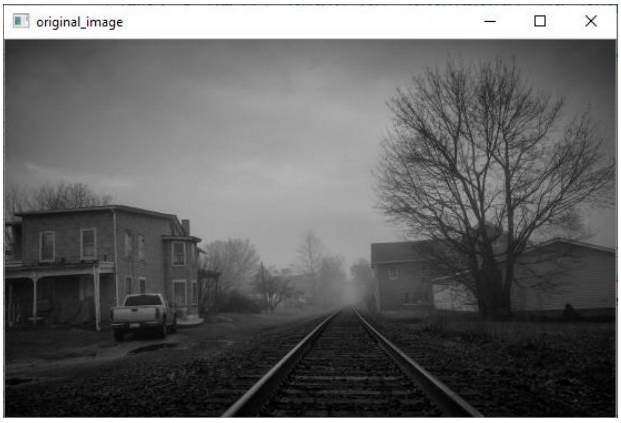
GIF FILTERING OUTPUT



WGIF FILTERING OUTPUT

SKWGIF FILTERING OUTPUT

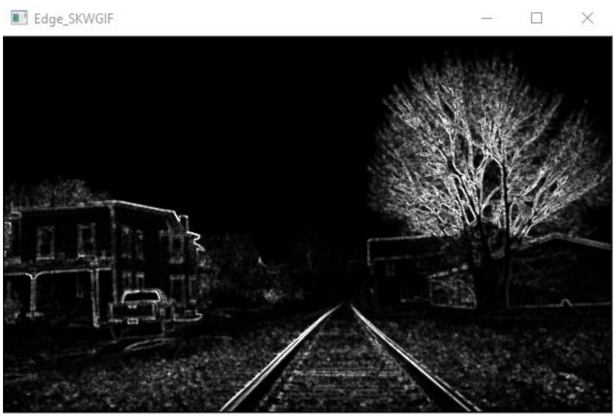
COMPARISON 2: ORIGINAL IMAGE



GIF FILTERING OUTPUT

WGIF FILTERING OUTPUT

SKWGIF FILTERING OUTPUT



- **Coloured Image Dehazing Using SKWGIF**

We have implemented image dehazing for coloured images using SKWGIF and Dark Channel Prior. Instead of using Laplacian matrix to refine the haze transmission map, we simply use SKWGIF to filter the raw transmission map under the guidance of the hazy image. The code uses Dark Channel Function, AtmLight Function, Transmission Refine and Recovery function along with SKWGIF function for guided image filtering. The results come out with a large amount of haze removed and visually similar to the original method while being a simpler algorithm and with less overhead.

<u>Code</u>

```
import cv2
from math import *
import numpy as np;

def DarkChannel(im,sz):
  """ This Function is used to get the pixel values
  whose intensity is very low in the given colour channel """
  b,g,r = cv2.split(im)
  dc = cv2.min(cv2.min(r,g),b);
  kernel = cv2.getStructuringElement(cv2.MORPH_RECT,(sz,sz))
  dark = cv2.erode(dc,kernel)
  return dark

def AtmLight(im,dark):
  """ This Function is used to estimate
  the atmospheric light in image"""
  [h,w] = im.shape[:2]
  imsz = h*w
  numpx = int(max(floor(imsz/1000),1))
  darkvec = dark.reshape(imsz,1);
  imvec = im.reshape(imsz,3);

  indices = darkvec.argsort();
  indices = indices[imsz-numpx::]

  atmsum = np.zeros([1,3])
  for ind in range(1,numpx):
    atmsum = atmsum + imvec[indices[ind]]

  A = atmsum / numpx;
  return A
```

```
def TransmissionEstimate(im,A,sz):
    """ This Function deletes the preliminary transmittal
    based on latent area obtained from dark channel"""
    omega = 0.95;
    im3 = np.empty(im.shape,im.dtype);

    for ind in range(0,3):
        im3[:,:,ind] = im[:,:,ind]/A[0,ind]

    transmission = 1 - omega*DarkChannel(im3,sz);
    return transmission

def Grad_func(img):
    '''
    This Function returns Local Gradient Matrices.
    Parameters
    ----------
    img : Image
        Input Image for which Local Gradient Matrices are to be found.

    Returns
    -------
    Grad_mat : 2D Numpy Matrix
            Matrix containing Local Gradient Matrix for every pixel in input image.
    '''
    dummy_mat = np.array([[0.00 for j in range(2)] for i in range(9)])
    Grad_mat = [[dummy_mat for j in range(img.shape[1])] for i in range(img.shape[0])]
    for i in range(1, img.shape[0]-1):
        for j in range(1, img.shape[1]-1):
            Gij = []
            roi = img[i-1:i+2, j-1:j+2]
            gx = cv2.Sobel(roi,cv2.CV_64F, 1, 0, ksize = 1)
            gy = cv2.Sobel(roi, cv2.CV_64F, 0, 1, ksize = 1)
            gx = np.reshape(gx,(9, ))
            gy = np.reshape(gy,(9, ))
            Gij.append(gx)
            Gij.append(gy)
            Grad_mat[i][j] = np.transpose(Gij)
    return Grad_mat

def steering_kernel(img):
    '''
    This Function Returns Steering Kernel Matrices.
    Parameters
    ----------
    img : Image

    Returns
```

```
    -------
    W : 2D Numpy Matrix
        Matrix containing Steering Kernel Weight Matrices for each pixel in input image.
    '''
    Grad_mat = Grad_func(img*255)
    dummy_mat = np.array([[0 for j in range(3)] for i in range(3)])
    W = [[dummy_mat for j in range(img.shape[1])] for i in range(img.shape[0])]
    for i in range(1, img.shape[0]-1):
        for j in range(1, img.shape[1]-1):
            u, s, v = np.linalg.svd(Grad_mat[i][j])
            v2 = v[1]
            if v2[1] == 0:
                theta = pi/2
            else:
                theta = np.arctan(v2[0]/v2[1])
            sigma = (s[0] + 1.0)/(s[1] + 1.0)
            gamma = sqrt(((s[0]*s[1]) + 0.01)/9)
            Rot_mat = np.array([[cos(theta), sin(theta)], [-(sin(theta)), cos(theta)]])
            El_mat = np.array([[sigma, 0], [0, (1/sigma)]])
            C = gamma*(np.dot(np.dot(Rot_mat, El_mat), np.transpose(Rot_mat)))
            coeff = sqrt(np.linalg.det(C))/(2*pi*(5.76))
            W_i = [[0 for q in range(3)] for p in range(3)]
            for n_i in range(i-1, i+2):
                for n_j in range(j-1, j+2):
                    xi = np.array([i, j])
                    xk = np.array([n_i, n_j])
                    xik = xi - xk
                    wik = coeff*(exp(-(np.dot(np.dot(np.transpose(xik), C), xik))/(11.52)))
                    W_i[n_i-i+1][n_j-j+1] = wik
            W[i][j] = W_i
    return W

def SK_Weighted_Guided_Image_Filter(im,p,r,r2,eps,lamda,N):
    '''
    This Function returns the output for Steering Kernel
    Weighted Guided Image Filter applied on Input Image.
    Parameters
    ----------
    im : Guidance Image

    p : Input Filter Image

    r : Radius of Kernel

    r2 : Radius of Local Window centered at a particular pixel

    eps : Regularization parameter
```

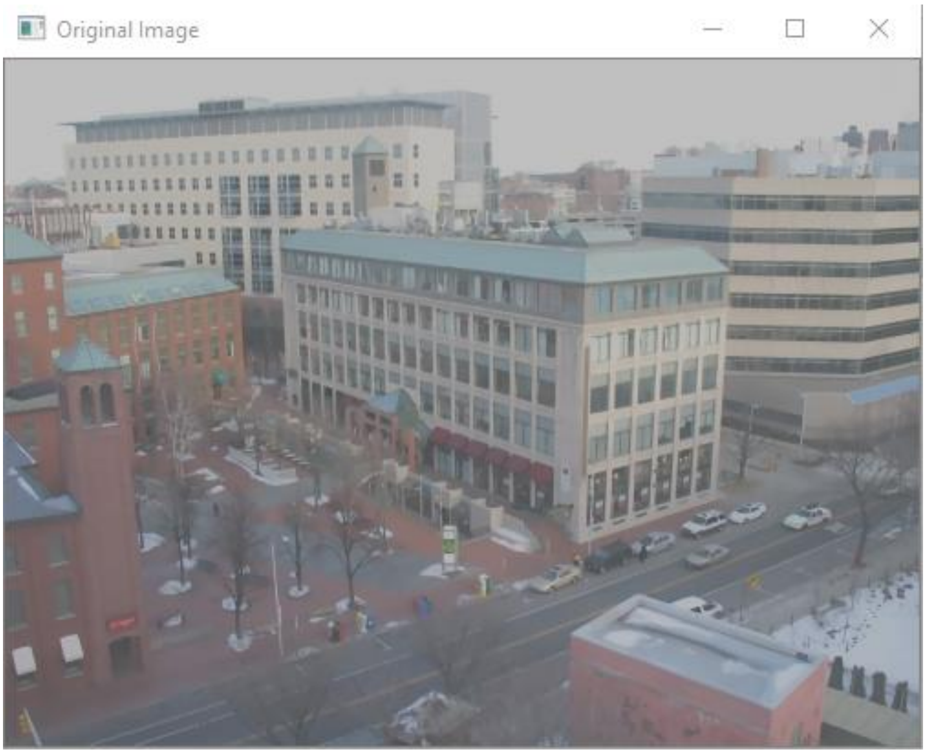
```
    lamda : small constant dependent on dynamic range

    N : Number of Pixels in the Input image
    Returns
    -------
    q : Output Image after SKWGIF application
    '''
    mean_I = cv2.boxFilter(im,cv2.CV_64F,(r,r))
    mean_I2  = cv2.boxFilter(im, cv2.CV_64F,(r2,r2))
    mean_p = cv2.boxFilter(p, cv2.CV_64F,(r,r))
    mean_p2 = cv2.boxFilter(p, cv2.CV_64F, (r2,r2))

    corr_I = cv2.boxFilter(im*im, cv2.CV_64F,(r,r))
    corr_I2 = cv2.boxFilter(im*im,cv2.CV_64F,(r2,r2))
    corr_Ip = cv2.boxFilter(im*p,cv2.CV_64F,(r,r))

    var_I = corr_I - mean_I*mean_I
    var_I2 = corr_I2 - mean_I2*mean_I2

    PsiI = ((var_I2+lamda)*np.sum(1/(var_I2 + lamda)))/N

    cov_Ip = corr_Ip - mean_I*mean_p

    a_psi = cov_Ip/(var_I + eps/PsiI)
    b_psi = mean_p - (a_psi)*mean_I

    W = steering_kernel(im)

    mean_a = [[0 for j in range(im.shape[1])] for i in range(im.shape[0])]
    mean_b = [[0 for j in range(im.shape[1])] for i in range(im.shape[0])]

    for i in range(1, im.shape[0]-1):
      for j in range(1, im.shape[1]-1):
        Wk = W[i][j]
        roi_a = a_psi[i-1:i+2, j-1:j+2]
        roi_b = b_psi[i-1:i+2, j-1:j+2]
        mean_a[i][j] = np.sum(Wk*roi_a)
        mean_b[i][j] = np.sum(Wk*roi_b)
    mean_a = np.array(mean_a)
    mean_b = np.array(mean_b)
    mean_b = b_psi
    #cv2.imshow("Edge_SKWGIF", mean_a)
    q = mean_a*im + mean_b
    return q

def TransmissionRefine(im,et):
    '''
    Parameters
```

```
    ----------
    im : Guidance Image

    et : Input Filter Image

    Returns
    -------
    t : Final image
    '''
    gray = cv2.cvtColor(im,cv2.COLOR_BGR2GRAY);
    gray = np.float64(gray)/255;
    r = 32;
    eps = 0.01;
    minimum = np.min(gray)
    maximum = np.max(gray)
    L = (maximum-minimum)
    lamda = (0.001*L)**2
    rows, columns = gray.shape
    N = rows*columns
    t = SK_Weighted_Guided_Image_Filter(gray, et, r, 3, eps, lamda, N);

    return t;

def Recover(im,t,A,tx = 0.1):
    """ This function recovers a haze-free image determined by three surface
    colour values as well as transmission value at every pixel."""
    res = np.empty(im.shape,im.dtype);
    t = cv2.max(t,tx);

    for ind in range(0,3):
        res[:,:,ind] = (im[:,:,ind]-A[0,ind])/t + A[0,ind]

    return res

fn = "Input Images Used\Building with Haze Color.jpg"
src = cv2.imread(fn);

I = src.astype('float64')/255;
dark = DarkChannel(I,15);
A = AtmLight(I,dark);
te = TransmissionEstimate(I,A,15);
t = TransmissionRefine(src,te);
J = Recover(I,t,A,0.1);

cv2.imshow("dark",dark);
cv2.imshow("Transmission Image",t);
cv2.imshow('Original Image',src);
cv2.imshow('Final Image',J);
```

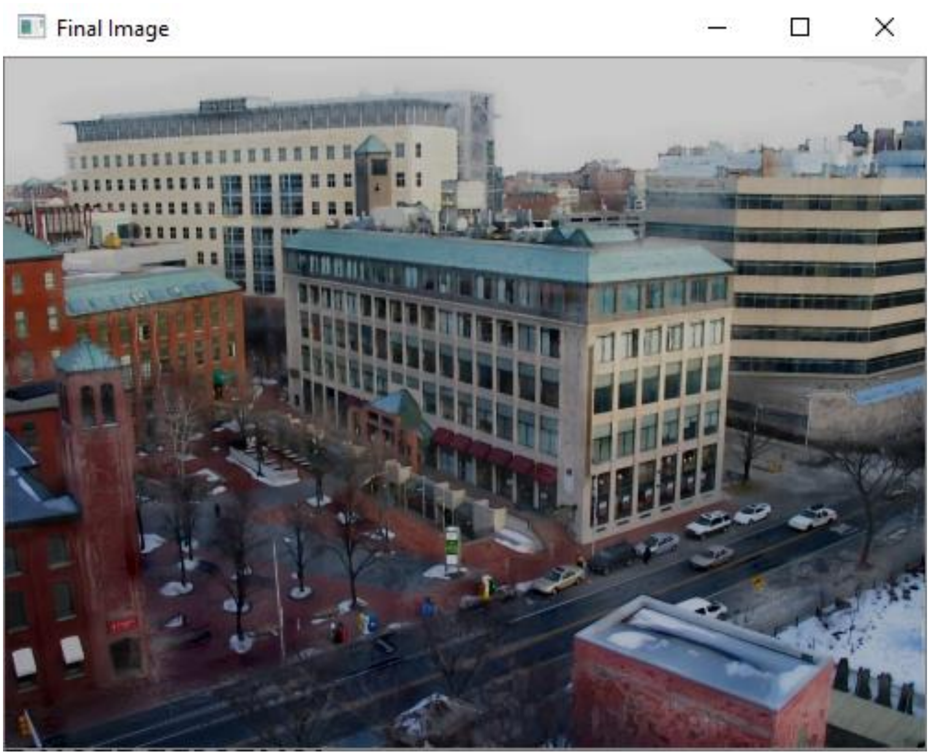
RESULT AND ANALYSIS

RESULT 1:

ORIGINAL IMAGE

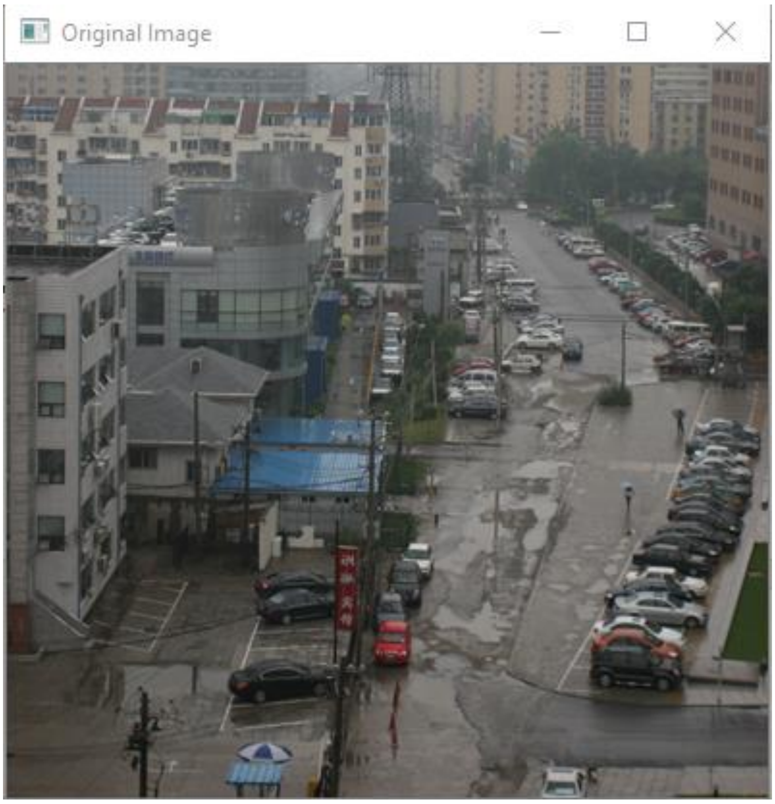


FINAL IMAGE AFTER HAZE REMOVAL



RESULT 2:

ORIGINAL IMAGE



FINAL IMAGE AFTER HAZE REMOVAL