Performance Investigation of digital filters for Image Enhancement

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Abstract: In poorly lit environmental conditions, the camera does not capture clear images. There are many enhancement processes for low light images, considering all those factors, it is inferred that the main problem that arises even after the enhancement process is the noise. Haze removal method is taken for the enhancement of the image after performing various studies on the various processes. Guided, Median, Gaussian and Weiner filters are deployed for removing the noise which is enhanced during the process in the low light image set. The performance analysis of the filters is carried out to measure the rate of enhancement with metrics such as SNR, PSNR and SSIM. The experimental results here show the performance of various filters taken into consideration and found that guided filter, median filter and wiener filter showed good enhanced results.

Keywords: low light image, noise, filters, analysis, enhancement.

1. Introduction
In this world, where everything is getting digitalized, digital images have its own importance. But cameras do not capture the images perfectly every time. Since they are also sensors, the quality of the images depends on various parameters such as the place where the subject of interest is present, amount of light, reflectance of light from the object etc. Hence, when we capture images under low light conditions, the image suffers due to low visibility, brightness, narrow gray range, low contrast, colour distortion and also significant amount of noise. Due to the presence of all these parameters degrade the quality of the image which in turn degenerates the performance of computer vision algorithms [1], [4]. Hence, we are in requirement of enhancement process that enhance images with good quality for various applications.

For enhancing the visual effect of low light images, subsequent processing of the image can be performed. Many methods were employed in this process and increasing the brightness of the image directly is the easiest way of bringing back the details of the dark regions. This in turn leads to the issue of saturating the bright regions leading to the loss of details in the image of interest. Histogram equalization is another method which is being widely used in this process of enhancement [1], [8], [9], [10] dealing the enhancement process through histogram would somehow avoid by forcing the image to fall under the range of [0,1]. Wavelet transformation or homomorphic filtering is deployed for enhancement with a non-linear operator [2] based on a hard or soft thresholding models. The other method which was employed was contrast variational method [11] adjusting the energy functions to pixel values of an input image directly so that the resulting histogram can be uniformly redistributed and the noise can be removed.
Gamma correction is another method of nonlinear operation on each pixel. This process does not consider the relationship of the pixel with its neighbours.

Among all these processes, we found out, that the image would be decomposed into reflectance and illumination is a perfect way of enhancing low light images called as Retinex concept [12]. Simple and an effective method was enhancement of low light images by illumination map, which dealt more concretely on the illumination of each pixel by finding the maximum value of the R, G and B channels. After the estimation process, refinement of the illumination map is carried out [13]. Recently, an enhancement process is also carried out by using Deep Neural Networks (DNN) [14] leading to the enhancement by deep hybrid network consisting of two streams for simultaneously learning the global content as well as the salient features of image in a same network [6].

The proposed work discusses the performance of filters like guided, gaussian, Weiner and median filters for the analysis of the filters. The noise present in the images is estimated to proceed with the enhancement process. The analysis of the filters is done to measure the image quality metrics.

The proposed paper is organized by four sections, section 2 deals with the elaboration of enhancement process, and their types. Section 3 elaborates the role and types of noise in the enhancement of images in image processing domain. The performance investigation of various filters is carried out in section 4 with the conclusion and the guide to the future work addressed in section 5.

2. Image Enhancement and Noise

Image enhancement is the process used for accentuating or sharpening the features of the images such as boundaries, edges and contrast for display. For enhancing the visual perception and the quality of the image this method is adopted. The main objective of this process is for achieving the desired result [8]. Spatial domain and frequency domain are the types of enhancement process. Spatial domain operates on the pixels of the image whereas the frequency domain operates by Fourier transform of the image.

Many enhancement algorithms [1] has been proposed for improving the quality and visual perception of the low light images in different perspectives [2] [3]. By the study conducted [5], the low light image enhancement process is classified into seven main classes: Histogram equalization, Gray transformation levels, Retinex theory, Defogging models, Frequency domain enhancement model, image fusion, Machine learning. Histogram equalization is one such method. When the values of the pixels in an image are distributed smoothly in every possible gray level [7], it then shows a high contrast. This also shows a large dynamic range. By this characteristic the Histogram equalization uses cumulative distribution for adjusting the gray levels for having a (PDF) probability density function which will give a uniform distribution, by which details hidden in the dark parts can reappear. The Retinex Theory is the theory of perception of colours by humans. This theory is for determining the object’s reflective nature by excluding the illuminating light in an image. The product of illumination and reflectance is the model of an image based on this theory. Further using this Retinex theory many algorithms were developed in enhancement of the images. In this paper, we have taken the haze removal technique for the enhancement process.

2.1 Haze removal method

The images captured in low light have low dynamic range along with high noise level. Haze removal method is taken for the enhancement; the histogram of the pixelwise inversion of the lowlight image is similar to the histogram of the hazy images. The haze removal algorithm follows three steps they are,

- Inversion of the input low light image
- Application of the haze removal algorithm to the inverted image
- Again, invert the image back to get the enhanced result.

The inversion process is done, to perceive how the low light areas in the image appear hazy. The representation of a hazy image is given as follows,
\[ I(z) = J(z)T(z) + L(1-T(z)) \quad (1) \]

\( I(z) \) – Intensity 
\( J \) - Scene radiance 
\( L \) - Atmospheric light 
\( T \) - Transmission map of the image

The dehazing algorithm just recovers the scene radiance by estimating the transmission map. The estimation of the atmospheric light \( A \) is,

\[ J(z) = (I(z)) - A)/(\max(t(z), t0)) + A \quad (2) \]

The algorithms that are applied here are: (SDC) simple dark channel prior, (ADCP) approximate dark channel prior. Unhazy images of the outdoor scene have pixels with low signal in either one or more channel. This dehazing algorithm follows five steps they are,

i) Estimation of the atmospheric light by dark channel prior algorithm

ii) Transmission map estimation is performed

iii) Obtaining the refined transmission map

iv) Restoring the image

v) Executing an optimal contrast enhancement

Images that are captured under low light conditions are enhanced by using the haze removal algorithm, which brings back the scene radiance and the atmospheric light. This process brings out the details of the dark regions.

2.2 Image Noise

Depending on the type of disturbance there would be presence of noise in images. These low light images too suffer from noises of different types and they do occur at different instances and also would have different effects in an image. The denoising is done using various filters and a complete study on the filters is performed for analysing the image quality metrics.

The sources of the noise in digital images occur during the capture of the images or the transmission of the image. The sensor’s performance is affected by environmental condition or the quality of the sensor itself. Some of the common noises that are said to be encountered, they are; Poisson noise, salt and pepper noise, speckle noise and Gaussian noise.

2.2.1 Gaussian noise: This noise is also known as additive noise, since this noise adds certain distribution to each and every pixel. The common type of distribution that is found in Gaussian distributions is the bell curve. This is caused mainly due to poor illumination when capturing the image or may be by the noise in the electronic circuit. The probability density function \( P \) of the Gaussian random variable is,

\[ P(Z) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(z-\mu)^2}{2\sigma^2}} \quad (3) \]

Where, \( Z \) is the grey levels, \( \mu \) - mean grey and \( \sigma \) – Standard deviation
2.2.2 Salt and pepper noise: Impulse noise is another name of this noise. Disturbances such as sudden fault in the charge coupled device or dust in the device during the capture of the images and directly affects few pixels.

\[
\text{Mean}(D(n))/\text{max}(D(n)) > \lambda \quad (4)
\]

Where, mean \( D(n) \) - mean of the dynamics of the grey levels of the homogeneous regions and Max \( D(n) \) is the maximum of the dynamics of the grey levels of the homogeneous regions

2.2.3 Speckle noise
This is a multiplicative noise. The distribution here multiplies with each pixel in the picture. This noise is caused due to random up and down from the signal of the objects. This also increases the gray levels of the image.

3. Performance analysis of Filters
Filtering of the image is necessary for removing the noise in an image. Filtering could be used for various purposes such as removal of noise, resampling and interpolation. Based on what type of noise is present in an image and what amount of noise is present in the image, filters should be chosen. The spatial domain has the following types of filters: max filter, median, gaussian, min, guided filter, BM3D filter (block matching and 3d filtering), linear filter, wiener filter we have taken some of the filters here for the analysis of the filters for the low light image enhancement.

3.1 Guided filter
This filter performs a smoothing by preserving the edges of the image. The filtering is done with the help of another image known as guidance image. The image itself could be the guidance image or a different version of the image could be the guidance image. A completely different image can also be a guidance image. This filtering operation here is a neighbourhood operation. This takes the statistics of the region into account corresponding to the spatial neighbourhood with respect to the guidance image while calculating the output pixel’s value.

3.2 Median filter
A pixel of an image is considered by the median filter and it searches for the neighbouring pixels for finding whether it’s is representing the surrounding. The median value is replaced instead of the pixel value. By sorting all the pixel values from all other surrounding neighbourhood by numerical order median is calculated. The pixel value is replaced by the middle pixel value which is very effective for removing salt and pepper noise.

3.3 Gaussian filter
The parameter \( \sigma \) in the gaussian filter controls the amount of smoothing. As the \( \sigma \) increases, more samples should be obtained to represent a gaussian function. The gauss function outputs the weighted average of each pixel present in the place of the central pixels. Applying this gaussian blur to the image and convolving is performed with gaussian function. The output of the gaussian of each pixel’s neighbourhood, along with the average weight is more towards the value of the central pixels. By applying the gaussian blur for an image by convolving image with gaussian function is given by

\[
G_{\sigma} = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{x^2+y^2}{2\sigma^2}\right) \quad (5)
\]
3.4 **Wiener filter**

This filter tailors adjust itself to the local image variance and calculate variance and local mean around the pixel.

\[
J = \text{wiener2}(I, [m, n], \text{noise})
\]

\([m, n]\) - size of the neighbourhood used for estimating the local image variance

This filters the image by using a low pass wiener filter. The filter performs smoothing if the variance obtained is large. It performs more smoothing if the variance obtained is small. Estimation of the local mean and the variance is given by,

\[
\mu = \frac{1}{MN} \sum_{n1,n2 \in \eta} \alpha(n1,n2)
\]

\[
\sigma^2 = \frac{1}{MN} \sum_{n1,n2 \in \eta} \sigma(n1,n2) - \mu^2
\]

\(\mu\) - local mean  \(\sigma\) - variance

\(\eta\) - \(N/M\) local neighbourhood of each pixel in the image.

Above are the filters for which the performance analysis is to be performed. These filters are to be analysed on the low light image which is enhanced by haze removal model. The image quality metrics and the comparison of the output of the images and their histograms is mentioned below.

4. **Proposed performance analysis for low light enhancement**

For initially enhancing the low light images, we have taken the Lowlight paired dataset (LoL). This dataset contains 500 low/normal light image pairs. The image pairs are been taken from real scene for low light enhancement. The format of the dataset is Portable Network Graphics (PNG) and the size of the image 400 x 600. This technique is performed by applying the haze removal technique and the procedure adopted is follows:

- We have taken few of the images from LoL dataset.
- The haze removal is performed on the images by using the haze removing method.
- After the enhancement is done it is found that the noise is also increased.
- For removing the noise, we are applying the filter approach for denoising. The filters that were taken were Gaussian filter, wiener filter, guided filter, median filter.
- Image quality metrics ensures the quality of all the filters.

After applying the filters, the quality of the resultant is measured by the quality metrics such as: PSNR, SNR, SSIM. The quality metrics are calculated for all the filters applied for removing the noise. And the histogram of the haze removed image and the filtered image are also compared. By taking an input image from the LoL dataset and enhancing the image by using the haze removal algorithm, the low light image is enhanced along with which the noise in the image is also enhanced, here comes the requirement of filters. Figure 1 represents result of guided filter on the enhanced low light image in which the input low light image is present. Figure 2 is the histogram comparison of the input image, enhanced image and the filtered results.
Comparison of haze removed image and guided filtered image

![Figure 1: A. input image B. haze removed C. filtered](image1)

Comparison of histogram of haze removed and histogram of guided filtered result

Based on the histogram obtained in Figure 2, A represents the histogram of the low light image, which shows peaks at the darker regions, B represents the histogram of the haze removed where it is widely dispersed in the bright regions also and the mid-tones of the image has mid-range values, C shows the histogram of the guided filtered image which is also widely dispersed. By the quality metrics of the filters we can infer the quality of the filter and which performs best. Similarly, Figure 3 and Figure 4 are the shows the input image, enhanced image, median filtered image and comparison of their histograms. The histogram C in the Figure 4 of the image with the median filtered image also shows a wide distribution range with the brighter regions having higher peaks than the guided filter. Figure 5 and Figure 6 Shows the input image enhanced image, wiener filtered image and comparison of their histograms respectively. Figure 6 shows the histogram of the wiener filtered image where the filter is applied after the enhancement of the image using haze removal algorithm, this result also shows a widely dispersed range along the bright regions and is

It is showing better range when compared to other two filters. Figure 7 and Figure 8 gives the input image, the enhanced image, Gauss filtered image and comparison of their histograms respectively. Figure 8 shows the histogram of the gauss filtered image, the histogram is distributed well but is not better than median and wiener filter. Other results based on the image quality metrics is given below.
Figure 3: a. Image (Input) b. haze removed c. filtered result

Comparison of haze removed image and median filtered result

Figure 4: a. Input’s histogram b. haze removed histogram c. Filtered result histogram

Comparison of histogram of haze removed image and histogram of median filtered result

Figure 5: a. Image (Input) b. haze removed c. Filtered result

Comparison of haze removed image and wiener filtered result
Experiments were performed by enhancing the low light images that were taken from the LoL dataset and on the enhanced image; denoising operation was performed to remove the noise which was enhanced during the process of enhancement. The Table 1 shows the image quality metrics of the filters and the resulting images.
metrics considered here are PSNR, SNR, and SSIM. Based these quality metrics which filter has showed best performance can be obtained.

**Table 1: Image quality metrics of the filters**

| S.No. | Image quality metrics | Input image 1 | Input image 2 | Input image 3 |
|-------|-----------------------|---------------|---------------|---------------|
|       | **Guided filter**     |               |               |               |
|       | PSNR                  | 19.2868       | 18.8492       | 21.2074       |
|       | SNR                   | 15.6674       | 12.5748       | 10.7092       |
|       | SSIM                  | 0.8446        | 0.6366        | 0.8472        |
|       | **Median filter**     |               |               |               |
|       | PSNR                  | 18.4260       | 18.8466       | 20.4574       |
|       | SNR                   | 14.8453       | 12.5517       | 9.8605        |
|       | SSIM                  | 0.7696        | 0.6456        | 0.7925        |
|       | **Wiener filter**     |               |               |               |
|       | PSNR                  | 19.5059       | 18.9085       | 21.1144       |
|       | SNR                   | 15.8629       | 12.6221       | 10.6354       |
|       | SSIM                  | 0.8524        | 0.6567        | 0.8367        |
|       | **Gauss filter**      |               |               |               |
|       | PSNR                  | 18.949        | 18.9288       | 19.6719       |
|       | SNR                   | 18.9288       | 12.4452       | 8.9244        |
|       | SSIM                  | 0.7332        | 0.5905        | 0.6931        |

By comparing the quality metrics based on the experiment conducted the PSNR of the guided filter shows better results when compared with other filters. The SNR of gauss filter has better results than the other filters. Various filters discussed above were applied on the enhanced image and their histograms are also obtained. Based on the comparison of the results of the histograms of the enhanced image and the various filters, median filter and wiener filter were found to give comprehensive results. When compared with the existing [15] study of noise removal techniques it is found that our proposed method is enhancing 10% more in guided filter.

**5. Conclusion**

With various studies on the enhancement techniques of the low light images, this paper proposes an enhancement method with the investigation of various filters and their performance on the enhanced results of the input image and also has measured various image quality metrics such as PSNR, SSIM, and SNR. By the experiments conducted and results of the image quality metrics, we found that guided filter and wiener filter showed better results when compared with other filters considered.
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