Enhancement of Dark Images in Presence of Optical Sources using Iterative Homomorphic Filter (IHF)

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***Abstract*- Most of the conventional enhancement schemes although produce better enhancement performances in case of dark images, they mostly fail to enhance the images in existence of optical sources. The regions with high intensity are excessively amplified and saturated, resulting in the loss of original information. So, there is a requirement to effectively regulate the illumination and reflectance component for proper enhancement of an image under challenging illumination conditions. In order to achieve effective enhancement under such conditions, an "Iterative Homomorphic Filter" is proposed which is made adaptive depending on the image types. The proposed filter attenuates the illumination component and enhances the reflectance component iteratively depending upon the overall average instantly of an image. The homomorphic filter outputs after 1st and pth iteration along with the original image are fused together to provide the enhanced output image which contains more information than the original. The experimental results display that the proposed technique shows improved enhancement efficiency for such images than most of the existing algorithms available in the literature in terms of subjective and objective measures.**

Keywords*- *dark image enhancement, homomorphic filtering, contrast improvement, image fusion

I. Introduction

Enhancing dark images is a crucial preprocessing technique in Image processing. Generally, Dark images often lack sufficient brightness and details, making it challenging to extract meaningful information out of it. Hence, these techniques aim to improve the clarity and quality of such images. There are several applications of Dark image enhancement which includes wildlife monitoring, traffic monitoring during night time, seat belt detection during night time, monitoring the intrusions in the international borders during night time, Air traffic monitoring, military applications, night vision camera and many more. With so many applications and potential, this process needs to be efficient so that it can be used in enhancing all types of images.

Dark images can be classified as: (a)Images which have inadequate lighting. (b)Images containing bright illumination source. The Image enhancement techniques address these issues by working on amplification of image content, enhancement of contrast, preservation of important details and noise artifacts reduction. Some of the classical enhancement techniques used in enhancement of dark images are discussed:

Histogram Equalization (HE) is a popular technique [1]. It redistributes pixel intensities in an image by computing the histogram, calculating the cumulative distribution function (CDF), mapping input intensities to new values using the CDF, and assigning the new intensities to the corresponding pixels. It flattens and stretches the dynamics range of the image's histogram and resulting in overall contrast improvement [2]. However, it was observed that in images containing optical sources, this technique fails as the region of optical sources and regions near it highly saturated.

The piecewise linear transformation is a linear mapping algorithm that works by dividing the input image into distinct regions based on different intensity levels. For each region, a linear mapping function is applied, which means that the pixel values within that region are adjusted according to the straight-line equation. This process is beneficial in enhancing the overall contrast of the image. By treating different intensity regions separately and applying appropriate transformations, the algorithm can effectively enhance the image's details and make it more visually appealing. However, the technique might fail in enhancing an image that contains a large number of non-linear regions especially if that contains an optical source. It is most important to select division points during the processing course of piecewise linear transformation because these division points can decide the quality and efficiency of image enhancement. But the proper division points are usually selected after several experiments which take a lot of time as described in [3].

Gamma correction is used to adjust the brightness and color balance of digital images by modifying the relationship between the pixel values and the displayed intensities. It involves applying a non-linear power-law function to the pixel values. But Gamma correction results in an unvaried modification result for every image because a predefined value of gamma correction factor γ and c is used for all kinds of images [4]. Selecting an appropriate value of γ can be challenging when dealing with an image with highly bright optical source.

Adaptive Gamma correction is a local enhancement technique that divides the image based on various regions. It involves gamma correction on a local/regional level where the local gamma value is determined based on the intensity of image region or pixel neighborhood.

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Although the classical methods are quite effective in enhancing the dark regions of an image but results in over enhancement and saturation around the highly intense bright regions like regions around the optical sources. The enhancement of dark images containing intense optical sources is a big challenge as the over-enhancement can lead to the loss of original information and degradation of image quality especially in regions near the bright source. Such images need to be handled carefully by not affecting the illumination component and increasing the darker regions simultaneously that requires both linear and non-linear mapping. In this paper, we address this issue by proposing a controlled image enhancement technique that can strike a balance between the retention of information we already have and reveal new information at the same time by reducing the illumination component and increasing the reflectance component and using the process of fusion to extract new information as suggested in [5].

II. PROPOSED TECHNIQUE

The purpose of this paper is to address the challenge of enhancing dark images containing intense optical sources without causing over-enhancement and saturation around the bright regions (optical sources).

A. *Iterative Homomorphic filtering*

In case of the proposed IHF technique, the global intensity of an input image is computed by averaging all the pixels of the image. The number of iterations of the homomorphic filter is determined based on the overall average intensity of the image. The iterative homomorphic filter attenuates the low frequency components which include the illumination component or the optical source and emphasizes the high frequency component or the reflectance component that carries more image information.

More information content of an image is revealed after each iteration. The final image is obtained by fusing the original image with the output image after 1st and final iteration. In this process, the original and the revealed information after enhancement are kept in one image and therefore produces better enhancement results.

In first iteration,the input is given by the user and in subsequent iterations, the output of previous iteration becomes the input of present iteration. The schematic diagram of this technique is depicted in Figure 2. There are three steps in the technique: (a) Global Average Intensity and allocation of filter parameter values (b) Homomorphic filtering (c) Image fusion.

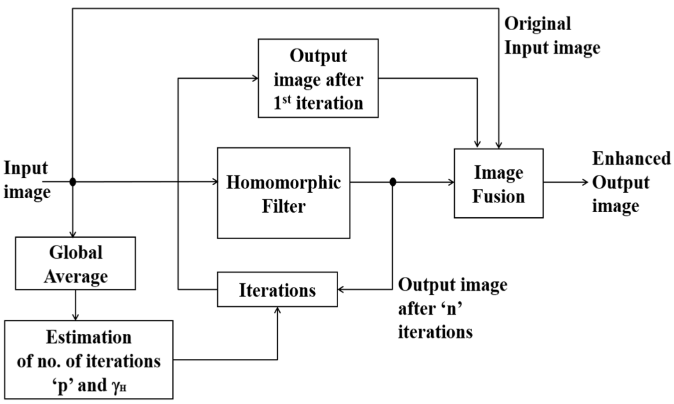

Figure 1: Block diagram of proposed Iterative Homomorphic Filtering (IHF)

In this technique, a grayscale image is taken as input. For this technique, four essential parameters are needed: the high-frequency gain 'γ_H' (reflectance component), the low-frequency gain 'γ_L' (illumination component). the cut-off frequency of the filter 'D_0' and the total number of iterations 'p'.

a) Global Average Intensity and allocation of filter parameter values:

Global average intensity is a measure of the average brightness level of an image. It is calculated by taking the mean intensity value of all pixels in an image. Mathematically,

$$\overline{f(x,y)} = \frac{1}{(R\times C)} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y) \quad (1)$$

Where, $f(x,y)$ is the Input image, R is the row , C is the column of the input image matrix. $\overline{f(x,y)}$ is the image global average intensity.

Based on the observation of an image dataset, images with a global average intensity less than 70 are considered as dark images with optical sources. If the global average intensity is greater than 145, the images are considered as bright images with optical sources. Images with a global average intensity between 70 and 145 are classified as mid-tone images.

This classification helps in determining the appropriate values for γ_H and total number of iterations p for image enhancement taking into account the brightness characteristics of the input image:

- For ($\overline{f(x,y)}$ < 70), γ_H= 2.53 and p=2
- For (70< $\overline{f(x,y)}$ < 145), γ_H= 1.58 and p=3
- For ($\overline{f(x,y)}$ > 145), γ_H= 1.38 and p=3

The value of γ_L is assigned 0.9 and remains the same for all cases.

In the subsequent iterations, the values of γ_L and γ_H change minutely and exponentially according to the following equations:

$$\gamma_{H(i)} = \gamma_{H(i-1)} e^{\left(\frac{(i-1)}{(2\sigma)^2}\right)} \quad (2)$$

$$\gamma_{L(i)} = \gamma_{L(i-1)} - \left(1 - \gamma_{L(i-1)}\right) e^{\left(\frac{-(i-1)}{(2\sigma)^2}\right)} \quad (3)$$

Where, $\gamma_{H(i)}$ = the value of γ_H at present iteration ' i ',
$\gamma_{H(i-1)}$ = the value of γ_H at previous iteration '(i-1)',
$\gamma_{L(i)}$ = the value of γ_L at present iteration ' i ',
$\gamma_{L(i-1)}$ = the value of γ_L at previous iteration '(i-1)',
σ = variance.

The purpose of this modification is to gradually change the value of γ_H and γ_L with increasing iterations (i) and control the rate of exponential increase and decay.

However, for the first iteration, the filter cut-off frequency (D_0) is initially assigned as 1500 for all cases. For the subsequent iterations:

- In dark images D_0 is assigned as 120.
- In mid-tone images and Bright images, D_0 is assigned 1500.

The parameters of IHF are selected on experimental basis after testing the algorithm on various types of images. The allocation of parameters is done to maintain a careful balance to ensure an effective enhancement avoiding any unwanted artifacts.

b) Homomorphic filtering:

Image comprises of two components, the illumination component and the Reflectance component. Mathematically, this is expressed as:

$$f(x,y) = l(x,y) \times r(x,y) \quad (4)$$

Where, $f(x,y)$ = the reflected light intensity from the point (x, y),
$l(x,y)$= illumination at that point,
$r(x,y)$ = the surface reflectance properties of the object at that point [6].

The domination of illumination component reduces the quality of an image. So, the improvement of an image's quality can be achieved by separating, then attenuating the illumination component and enhancing the reflectance component. Hence, a homomorphic filter is used for the purpose. Stages involved in the Homomorphic filtering:

- **Stage 1:** The image is subjected to a logarithmic transformation.
  $$q(x,y) = \ln\{l(x,y)\} + \ln\{r(x,y)\} \quad (5)$$
- **Stage 2:** The image is converted to frequency domain from spatial domain.
  $$\Im\{q(x,y)\} = \Im\{\ln\{l(x,y)\}\} + \Im\{\ln\{r(x,y)\}\}$$
  $$\Rightarrow\ Z(u,v) = L(u,v) + R(u,v) \quad (6)$$
- **Stage 3:** Homomorphic filter uses a combination of both high pass as well as a low pass filter. to pass all the required frequency components(mostly high frequency) for a better enhanced image.
  The Transfer function of the filter *H(u,v)* is given as:
  $$H(u,v) = (\gamma_H - \gamma_L)\left[1 - e^{-c\left(\frac{D(u,v)}{D_0}\right)^2}\right] + \gamma_L \quad (7)$$
  where constant c is to control the steepness of the slope, D_0 is the cut-off frequency, γ_H is the high frequency gain, γ_L is the low frequency gain, $D(u,v)$ is the distance between coordinates (u,v) and the centre of frequency at (0,0) [7].
  The image is passed through the filter $H(u,v)$ to get filtered image $S(u,v)$
  $$S(u,v) = H(u,v) \times Z(u,v) \quad (8)$$
- **Stage 4:** The filtered image is subjected to an inverse Fourier Transform to convert image back into spatial domain $s(x,y)$.
  $$s(x,y) = \Im^{-1}[S(u,v)] \quad (9)$$
- **Stage 5:** The enhanced original image is obtained by taking the exponential of $s(x,y)$.
  $$g(x,y) = e^{s(x,y)} \quad (10)$$

The output of every iteration of homomorphic filtering is used as the input for next iteration. It happens till all the assigned number of iterations of homomorphic filtering are completed.

c) Image fusion

Input image, first iteration output and final iteration output are fused together. This is done by taking the average of the three images.

$$k(x,y) = \frac{1}{3} \times [f(x,y) + g_1(x,y) + g_f(x,y)] \quad (11)$$

Where, $k(x,y)$= Fused output image
$f(x,y)$ = Input Image
$g_1(x,y)$ = 1st iteration output
$g_f(x,y)$ = Final iteration output

This process is done to combine the three images and generate a fused image that preserves the best features from the three images ie. quality like original image and the new information from first and final iterations. This process plays a crucial role in enhancing the visual quality as well as extracting relevant information from input images.

B. Flow-Chart of the proposed IHF technique..

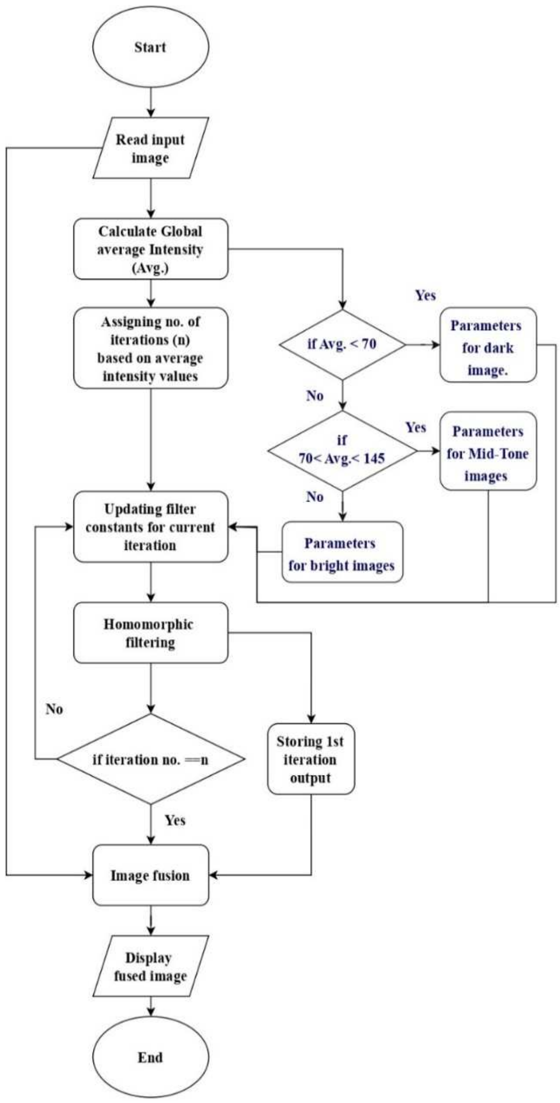

Figure 2: Flow-Chart illustrating Proposed Technique

C. Algorithm of the proposed IHF technique

Step 1: Take grayscale image input.

Step 2: Calculate Global average intensity using (1).

Step 3: Allocate IHF parameter values according to the Global average intensity of the input.

Step 4: Perform 1st iteration of homomorphic filtering

Step 5: Display and store the output in a variable.

Step 6: Update homomorphic filter parameters using (2) and (3).

Step 7: Perform the subsequent iterations of homomorphic filtering with previous iteration outputs as inputs and updated parameters.

Step 8: Display all iteration outputs and store the final iteration output in a variable.

Step 9: Take average of input, first iteration and final iteration output to get a fused image using (8).

III. Result Analysis

The dataset used for evaluation consists of a combination of images sourced from the Exclusively-Dark-Image-Dataset, and images captured by smartphone camera. All images contain at least one direct bright optical source. These images represent a diverse range of visual characteristics, including different scene types, object complexities, and lighting conditions. These images were selected for both subjective and quantitative assessment. Apart from these, Figure. 8 is used to illustrate the variation of histogram in every iteration. The results of the proposed technique were compared to that of several existing techniques like Histogram Equalization (HE), Gamma Correction (GC), Local Adaptive Gamma Correction (LAGC), Piecewise Linear Transformation (PLT).

A. Histogram variation after every iteration in proposed technique.

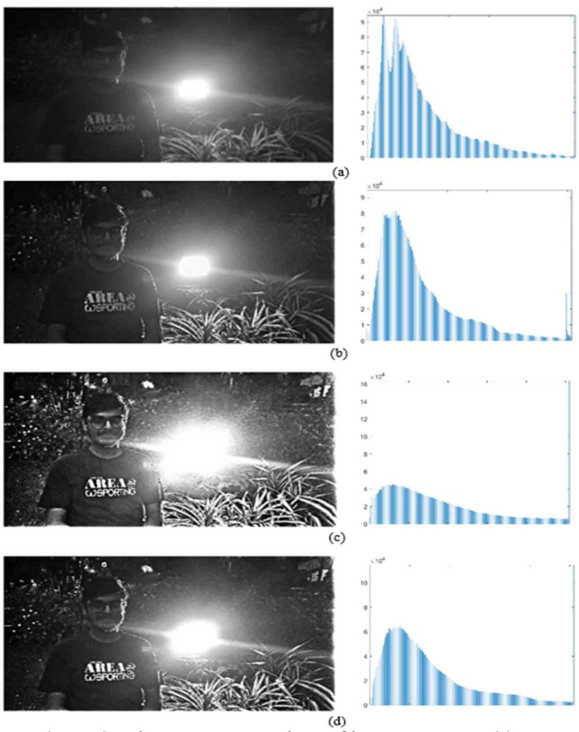

Figure 3: Histogram Comparison of image 'Person': (a) Input and it's histogram (b) 1st iteration output and it's histogram (c) 2nd iteration output and it's histogram (d) Fused image and it's histogram

In figure3, we can see that histogram of the image flattens after every iteration of IHF which shows the effective distribution of pixel intensities.

B. Subjective evaluation

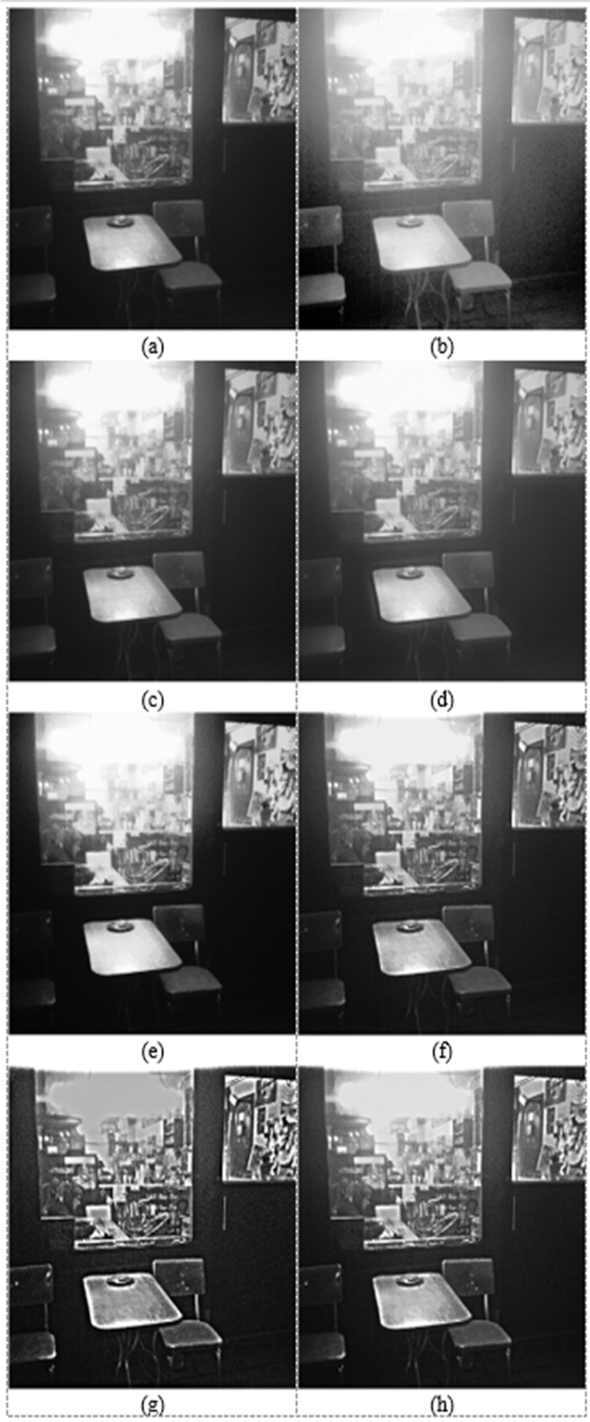

Figure 4: Subjective evaluation of "Table": (a) Input (b) HE, (c) GC, (d) LAGC, (e) PLT, (f) 1st iteration IHF, (g) 3rd iteration IHF, (h) Fused image after IHF

Figure 4 illustrates the subjective evaluation for a midtone image. In HE, although the table and chair is effectively enhanced, the region near the window is hazy due to the presence of the tube-light and a very little information is visible. Other techniques are also not successful in enhancing the region near tube-light. As compared to the rest of the techniques, proposed technique effectively contains the illumination of tube-light and enhances the nearby objects like the man sitting close to the window.

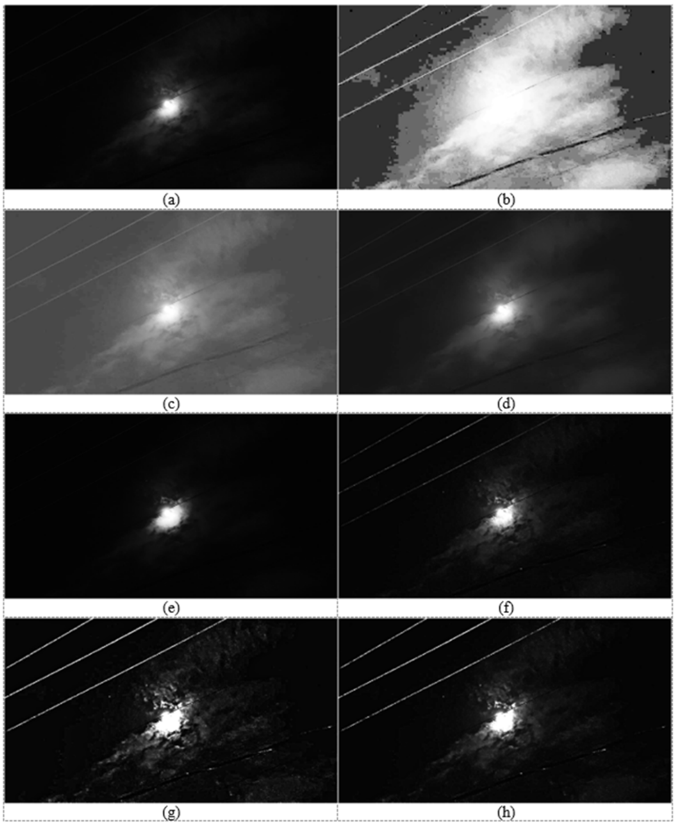

Figure 5: Subjective evaluation of "Night": (a) Input image, (b)HE, (c)GC, (d) LAGC, (e) PLT, (f) 1st iteration IHF, (g) 2nd iteration IHF, (h) Fused image after IHF

Figure 5. illustrates the subjective evaluation for a dark image. It can be observed that in HE the image is completely distorted. In GC, the image has a very little enhancement and the overall appearance is hazy. AGC and PLT almost show no enhancement in image. However, it can be observed that proposed technique is able to extract new information like here the wires and details of cloud near the optical source ie. the moon It successfully contains the luminance of the optical source and enhances the surrounding regions effectively after every iteration.

C. *Quantitative Evaluation*

To depict the performances and outcomes of the proposed technique compared to other techniques, some image quality metrices in particular, like the AMBE (Absolute Mean Brightness Error) and the RMSC (Root mean square contrast) were calculated. The chosen image metrics have proven to be reliable indicators of image quality and has been used by many researchers. A Dataset of five images were taken for quantitative evaluation.

a) Absolute Mean Brightness Error (AMBE)

Absolute Mean Brightness Error (AMBE) is a metric that can be used for evaluation of the quality of output image with respect to the original input image. It is computed by obtaining the absolute value of the difference between the global average intensities of the original and enhanced image.

Mathematically, it can be represented as:

$$AMBE = \left|\overline{f(x,y)} - \overline{k(x,y)}\right| \tag{11}$$

Where, $f(x,y)$ and $k(x,y)$ represent original input and processed output image respectively, $\overline{f(x,y)}$ and $\overline{k(x,y)}$ denote the average brightness of original input and processed output image respectively.

An increase in AMBE signifies a higher difference in brightness levels between the original and enhanced images. While a higher AMBE value may indicate better enhancement, it also implies an increase in the intensity of the luminance of optical sources. Therefore, a lower AMBE value is desirable, indicating that the brightness value of the enhanced output image closely matches to that of the original input image and the luminance of the optical source is effectively contained.
Table-1 illustrates comparison of AMBE values of proposed technique with other techniques.

TABLE 1. QUANTITATIVE EVALUATION IN TERMS OF AMBE

Images	HE	GC	LAGC	PLT	IHF (1st iteration)	IHF (Final iteration)	IHF (Fused)
Night	116.4	78.1	21.8	3.1	1.7	6.4	3.6
Table	39.9	6.7	21.9	1.9	0.7	9.04	2.2
Person	61.4	55.3	18.6	3.6	1.9	23.1	11.4
City	19.7	7.3	32.2	22.1	4.5	35.9	13.3

It can be seen from Table-1 that the AMBE values of proposed method are consistently less than that of HE, GC and LAGC. While, the AMBE value of PLT is lesser than the proposed technique in majority of these cases, it is unable to extract the hidden information whereas the proposed technique also extracts the hidden information.

b) Root Mean Square Contrast (RMSC)

Root Mean Square Contrast (RMSC) is the variation of contrast within an image. It quantifies how much brightness values of pixels in an image differ from the average brightness of the image. It is mathematically expressed as:

$$RMSC = \sum_{i=0}^{R-1}\sum_{j=0}^{C-1}\sqrt{\frac{1}{(R\times C)}\times\left[\overline{k(x,y)} - k(i,j)\right]^2} \tag{12}$$

Where, R and C represents the rows and columns in the image matrices respectively and $\overline{k(x,y)}$ depicts the global average intensity of the enhanced output image and $k(i,j)$ depicts the pixel intensity at i^{th} row , j^{th} column.

TABLE 2. QUANTITATIVE EVALUATION IN TERMS OF RMSC DIFFERENCE

Images	HE	GC	LAGC	PLT	IHF (1st iteration)	IHF (Final iteration)	IHF (Fused)
Night	0.52	0.31	0.09	0.02	0.03	0.09	0.07
Table	0.19	0.02	0.09	0.07	0.05	0.16	0.08
Person	0.24	0.20	0.07	0.07	0.06	0.20	0.15
City	0.11	0.02	0.13	0.10	0.04	0.17	0.09

The RMSC of the proposed technique is compared with other techniques, as shown in Table 2. It can be seen that the RMSC of the resulting image increased after each iteration. Notably, the RMSC of the proposed technique exhibits better performance compared to PLT and is nearly on par with LAGC. However, it is important to highlight that HE and GC yields slightly better contrast enhancement compared to the proposed technique. Nevertheless, it is worth noting that the resulting images from HE and GC exhibit distortion and scattering effects.

IV. CONCLUSION

The proposed IHF algorithm effectively enhances dark images in presence of optical sources. The dominance effect of optical source is reduced iteratively by attenuating the illumination component which is a low frequency component. Furthermore, the darker regions which contain the unveiled information is properly revealed by enhancing the reflectance component through iterative homomorphic filtering. Experimental results show that the image intensity distribution is more flattened leading to overall contrast improvement of an image through this process. In most of the existing scheme like HE, there is an over-enhancement or saturation effect observed in the bright regions leading to loss of original information. In contrast, the proposed algorithm enhances the darker regions as well as preserves the original formation without any saturation effect at the brighter regions. In addition to it, being a semi-adaptive scheme, the proposed algorithm works well with bright and midtone images and hence is versatile. Therefore, the proposed scheme is a suitable candidate for applications such as Real-time night driving assistant, Night vision camera, Night traffic monitoring, Seat belt detection, Automatic Road-toll collection, Surveillance etc.

APPENDIX

Some more images whose performance metrices were calculated and evaluated above are as follows:

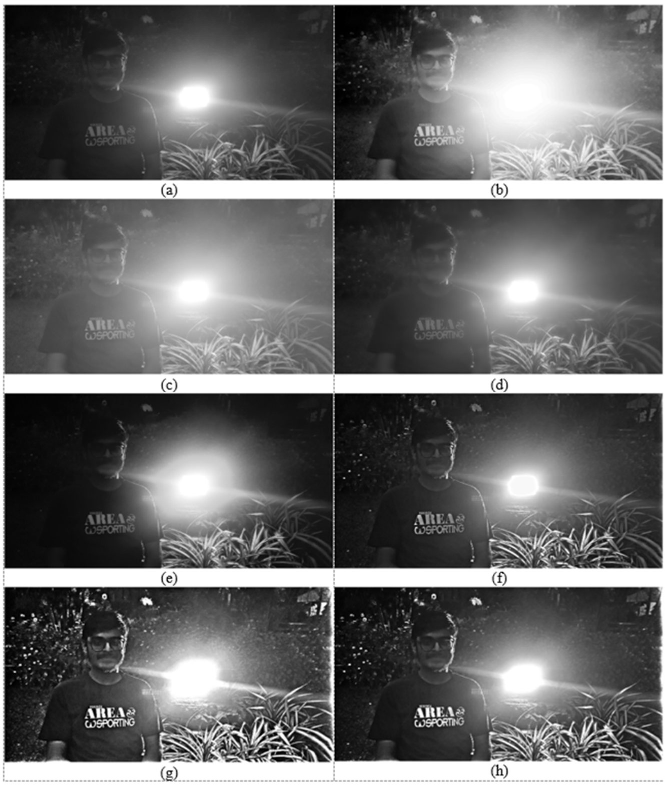

Figure 6: Subjective evaluation of "Person": (A) Input image, (B)HE, (C)GC, (D) LAGC, (E) PLT, (F) 1st iteration IHF, (G) 2nd iteration IHF, (H) Fused image after IHF

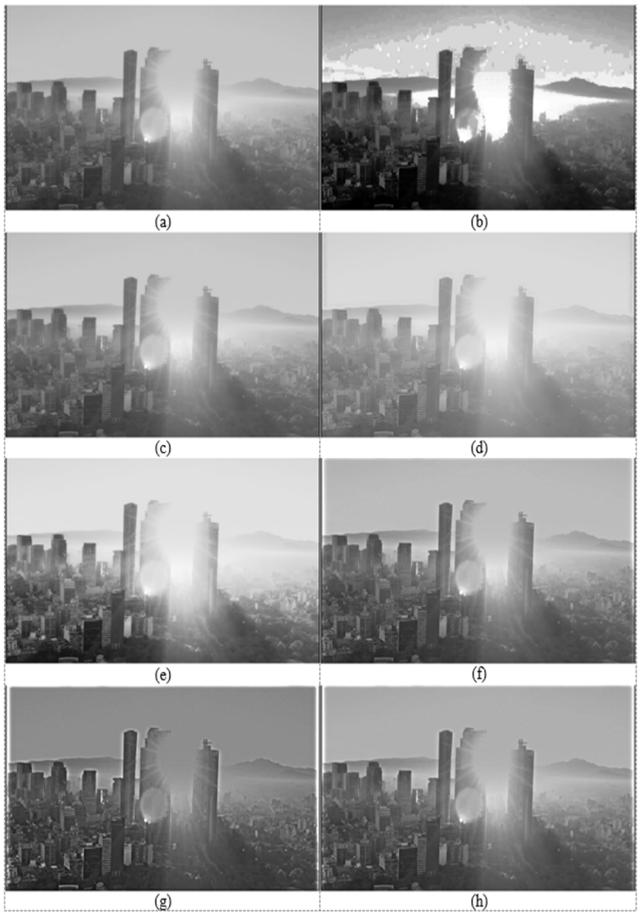

Figure 7: Subjective evaluation of "City": (a) Input (b) HE, (c) GC, (d) LAGC, (e) PLT, (f) 1st iteration IHF, (g) 3rd iteration IHF, (h) Fused image after IHF

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