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Improved Low Vision Image Enhancement Algorithm (ILVIE) for Wireless Multimedia Sensor Network

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Abstract

The low visibility of a captured image at image sensor node is critical issues of wireless multimedia sensor networks (WMSN) . It is observed that low light images significantly diminish the performance of many computer vision and multimedia applications. To outfit this issue, we propose an Improved Low Vision Image Enhancement Algorithm (ILVIE) to get better visual quality of an image. A novel algorithm is designed by considering the illumination map of R, G, and B components of an image to improve visual quality. The experimental result found improvement in the performance of the system and also computation complexity is very less which is best suitable for wireless multimedia sensor network.

Keywords: Wireless Multimedia Sensor Networks, WMSN, Improved Low Vision Image Enhancement, ILVIE.

INTRODUCTION

High visibility images exhibit detailed information of the captured images, which are crucial to many multimedia [1], surveillance [2] and object tracking [3] applications. But the problem arises when the image captured in varying environment conditions such as image captured in dark condition suffer from visibility issue. In figure 1 first row shows images captured in low light images suffer from visibility issue. In such scenarios we need to use image enhancement technique to get better visibility of the captured images which is shown in third row figure 1.

Direct enhancement of low light image is to amplify dark region of an image. But this will emerge new critical problem, say bright regions may be oversaturated and degrade the visible information. Simple way to get good visibility of dark region is to apply direct amplification to the image captured in low light scenarios. But this lead to era of new problem, say high intensity regions are over saturated and thus loss valuable information. Somehow this problem can be eliminated by applying Histogram Equalization techniques [4]-[6]. CVC method [7] finds histogram mapping that concentrate on difference in large gray levels. These techniques concentrate only on contrast enhancement rather than exploring illumination changes, this lead to over enhancement and under enhancement problems. The alternate solution is to use a nonlinear operation using gamma correction (GC) on images but the problem is that, the gamma correction is applied to every pixel irrespective of relationship between neighboring pixel values. Thus the enhanced image may suffer to maintain visual consistency.

Figure 1. First row: Natural images captured in low light. Second row: The estimated illumination map by proposed method. Third row: Enhanced results of proposed methods.

Reflectance and illumination are the two factors that can decompose the image using the assumption of retinex model [8]. Single scale retinex [9] model consider the reflectance as criteria to enhance the image. The resultant image look like unnatural and over saturated. Multi scale retinex [10] model replicates same functionality and result. The fusion based image enhancement method [11] initially estimates the illumination matrix to tune illumination of enhanced image. The results of this technique are very impressive but blindness in constructing illumination map may degrade the quality in regions which contain rich texture.

Our Contribution: Our technique is similar to Retinex – based image enhancement methods, which uses illumination matix to improve the visual quality of the image. Our work consider only illumination factor which will greatly reduce the computational complexity as compared to traditional retinex based methods [12] that consider both reflectance and illumination. To form illumination map we consider average value of red, green and blue channels. Then reframe the illumination by using initial illumination map. Finally a novel fast solver algorithm is developed to minimize the computational complexity.

PROPOSED WORK

Our method is based on following model, which explains the formula for an image captured in low light condition.

$$X = Y \, o \, Z. \tag{1}$$

Where X and Y are the captured image and required recovery for enhancement respectively. Z indicates the illumination map and the *o* operator represents element by element multiplication.

In our work, we believe that, three channel present in color image share common intensity map for color images. We use Z to represent any one of the three channels and $\bar{Z}$ represent all three channel illumination maps respectively. From equation (1) we can say the captured image can be in the form of product of intensity map and light enhanced scene.

The intrinsic decomposition [13][14] has similarities with our proposed problem. But intrinsic decomposition tries to deteriorate input image into two components (shading and reflectance). In intrinsic image decomposition [13] reflectance disturb the structure of the image, which is not suitable for visual enhancement of an image. The aim of our work is to enhance the visual representation of low intensity pixel regions without disturbing the visual clarity.

A. Estimating Illumination Map

One of the best methods, by considering the maximum intensity values of channels, say red, green and blue is retinex theory of color vision [8] which tries to approximate illumination map. Only global illumination can be enhanced using this technique. In this paper we use following illumination map to handle non-uniform illumination:

$$\bar{Z}(m) \leftarrow \underset{c\epsilon\{R,G,B\}}{AVG} \; X^c(m) \tag{2}$$

for each individual pixel m in all three channels. The key behind above equation is that the illumination is at least the average value of red, green and blue channels at any location. The obtained illumination map $\bar{Z}$ ensures that the recovered image will not be over saturated. Because of the following equation

$$X(m)/\left(\underset{c\epsilon\{R,G,B\}}{AVG} \; X^c(m) + \epsilon \right) \tag{3}$$

Where $\boldsymbol{\epsilon}$ is a minute constant value used to eliminate zero denominator. We clearly mention that the main goal of this technique is to balance enhancement in non-uniform illumination of image captured under low light instead of improving global illumination.

In our work, to estimate initial illumination map $\bar{Z}$ we use equation (2), although various methods have been implemented ([15]-[17]). All these methods consider local illumination by considering nearby pixels. Two ways to find initial illumination map are:

$$\bar{Z}(m) \leftarrow \underset{n\epsilon\Omega(m)}{max} \cdot \underset{c\epsilon\{R,G,B\}}{AVG} \; X^c(n) \tag{4}$$

Where $\Omega(m)$ is location index within the pixel region centered at m and n. The above equations can consider only local consistency. To tackle this issue, we present following optimization problem:

$$\underset{Z}{min} \|\bar{Z} - Z\|_F^2 + \beta \|Vo\nabla Z\| 1 \tag{5}$$

Where β is the constant to balance two values involved and ‖.‖ F and ‖.‖1 are the Frobenious and *l*1 norms respectively. Weight matrix is denoted by V and first order filter∇Z. In equation (8), the first component tunes constancy between initial illumination map $\bar{Z}$ and retuned illumination map Z, while the second component focuses on image smoothness. To build weight matrix, we have designed fast solver to fix the problem (5).

B. Fast Solver to problem (8)

The weighted gradient term $\|Vo\nabla Z\|1$ is origin from iterative procedure. Combination of gradient operation Z with *l*1 norm makes it complex. The below relationship holds true:

$$\lim_{\epsilon \to 0^+} \sum_m \sum_{d\epsilon\{t,u\}} \frac{V_d(m)\left(\nabla_d Z(m)\right)^2}{|\nabla_d Z(m)| + \epsilon} = \|Vo\nabla Z\|_1 \tag{6}$$

From above equation, we can replace $\|Vo\nabla Z\|_1$ by $\sum_m \sum_{d\epsilon\{t,u\}} \frac{V_d(m)\left(\nabla_d Z(m)\right)^2}{|\nabla_d Z(m)| + \epsilon}$. Now the problem (5) can be written in the form:

$$\underset{Z}{min} \|\bar{Z} - Z\|_F^2 + \beta \sum_m \sum_{d\epsilon\{t,u\}} \frac{V_d(m)\left(\nabla_d Z(m)\right)^2}{|\nabla_d \bar{Z}(m)| + \epsilon} \tag{7}$$

The aim of finding structure of illumination from initial illumination $\bar{Z}$ is unchanged even though we modify proposed optimization problem. When $|\nabla_d \bar{Z}(\boldsymbol{m})|$ is very small, then $|\nabla_d \boldsymbol{Z}(\boldsymbol{m})|$ is suppressed. In Contradictory, if the value of $|\nabla_d \boldsymbol{Z}(\boldsymbol{m})|$ is large, the suppression is reduced, because this, it is increased towards boundary structure than on regular value.

It is evident that the equation (7) can contain quadratic terms. This can be solved using following:

$$\left(I + \sum_{d\epsilon\{t,u\}} D_d^Z Diag(\tilde{v}_d) \, D_d\right) Z = \bar{Z} \tag{8}$$

Where $\tilde{v}_d$ is vectored version of $\tilde{V}_d$ with $\tilde{V}_d$(m) $\leftarrow \frac{V_d(m)}{|\nabla_d \bar{Z}(m)| + \epsilon}$. Diag(m) is the diagonal matrix using vector m.

C Generating Weight Matrix

Weight matrix V plays a key role in setting up initial illumination map. We have identified two different methods:

Method I: By using *l*2 loss minimization problem [33] weight matrix can be set as follows:

$$V_t \leftarrow 1; \quad V_u \leftarrow 1 \tag{9}$$

Method II: We can use weight matrix as a gradient of the initial illumination map. Because the Z is designed to avoid forming a gradients and initially calculated illumination map has very minute value of gradient.

$$V_t(m) \leftarrow \frac{1}{|\nabla_t \bar{Z}(m)|+\epsilon}; \qquad V_u(m) \leftarrow \frac{1}{|\nabla_u \bar{Z}(m)|+\epsilon} \qquad (10)$$

Improved Low Vision Image Enhancement Algorithm (ILVIE): When we have rectified illumination map Z, we can recover Y and also use gamma correction to modify the illumination map ($Z \leftarrow Z^{\gamma}$). Once we enhance dark regions, noises hidden in the dark regions are highlighted. To refine the visual quality of the image denoising is utilized. Many denoising techniques are available [18]-[20] to remove the noise. We have adopted BM3D [18] on Y channel by transforming RGB to YUV color space to save computational load. We use following equation to remove noise:

$$Y_f \leftarrow Y \, o \, Z + Y_d \, o \, (1 - Z) \qquad (11)$$

Algotithm :

Input: Low light Image X.

1. Generate weight matrix by using Eq. (9) or Eq. (10).
2. Find initial illumination map $\bar{Z}$ on X via Eq. (2).
3. Rectify illumination map Z using $\bar{Z}$ using fast solver Eq. (8).
4. Perform Gamma Correction on Z via Z← Z^{γ}.
5. Intensify X using Z. Where , $X = Y \, o \, Z$.
6. Using BM3D denoise and recompose the image via Eq. (11).

Output: Enhanced image.

EXPERIMENTAL RESULTS

In this segment we compare our technique with several image enhancement techniques like Histogram equalization (HE)[4] , Gamma Correction (GC) [22] , Variational Contrast Enhancement(CVC) [7] and Adaptive Histogram Equalization (AHE), Naturalness Preserved Enhancement algorithm (NPE)[21], Simultaneous Reflection and Illumination Estimation (SRIE)[12].We have implemented using Matlab which shows computation time of above techniques.

As shown in figure 2 AHE and CVC are not effectively recollecting the information of an image in dark regions. But HE, NPE and SIRE comparably produce better results than AHE and CVC. But our method outperforms above methods in terms visual quality of reconstructed image.

We have performed another test which is shown in figure 3. Noise is hidden in low light images, after enhancing the image using ILVIE, details of the image get enhanced but there will be exhibition of noise which can be observed in figure 3(c). This is common problem in almost all image enhancement algorithms. Image in figure 3(d) is a denoised image after application of BM3D which we can see improved visual quality in the image.

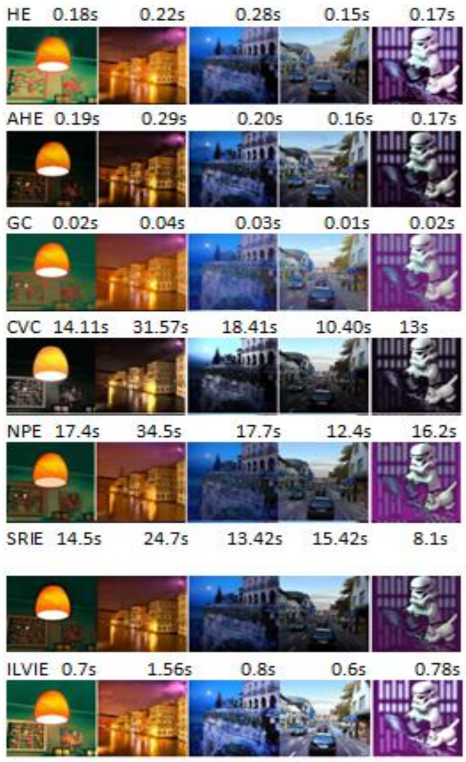

Figure 2. Computation time comparison and Quality of enhanced image between AHE, HE, CVC, GC and our technique

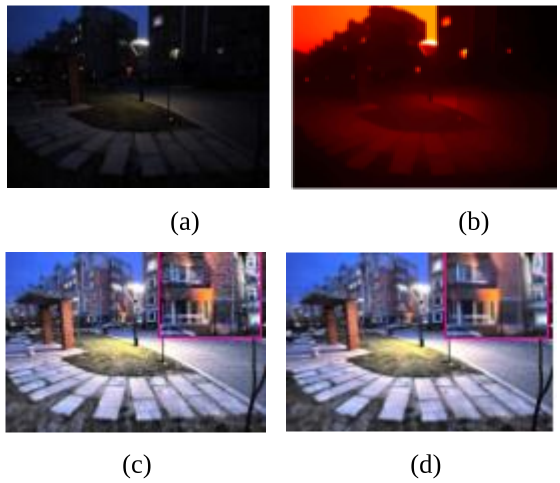

Fig.3. Comparison of enhanced image with noise and without noise. (a) Input image (b) Illumination map of a given image (c) Enhanced image with noise (d) Enhanced image without noise.

As discussed in [21] , order of lightness in different regions of an image decides quality of naturalness of an image. To measure the performance of enhanced image we use lightness order error (LOE) as a quality measure.

The equation of LOE is as follows:

$$\text{LOE}=\frac{1}{t}\sum_{m=1}^{t}\sum_{n=1}^{t}\Big(U\big(Q(m),Q(n)\big)\oplus U\big(Q_r(m),Q_r(n)\big)\Big) \qquad (12)$$

The term, U(p,q) = $\begin{cases} 1, & if\ p \geq q \\ 0, & otherwise \end{cases}$.

Where, t is pixel number and the operator ⊕ represents ex-or operation. The average value of R, G and B channels are represented by $Q(m)$ and $Q_r(m)$ at location m of the final enhanced and reference image. To get better visual quality of an image LOE must be as low as possible.

Table 1. Performance comparison of LOE.

Method	BabyAtWin	ChrisRider	HighChair	BabyonGrass
HE	4.53	2.43	3.12	4.49
AHE	3.48	2.12	1.91	2.47
GC	4.51	2.43	3.14	4.49
CVC	4.54	2.55	3.14	4.48
NPE	3.81	3.19	3.40	4.48
SRIE	4.13	2.77	3.20	4.22
ILVIE	3.21	1.92	1.85	2.25

Table 1 shows the LOE of existing methods and proposed method by considering different images. Figure 3 shows graphical representation of LOE , our method provide very low LOE in comparison with existing methods.

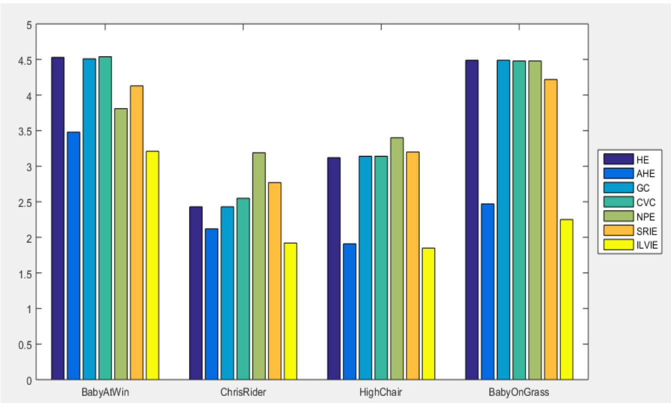

Figure 3. LOE graphical representation.

CONCLUSION

In this paper, we proposed a novel approach which is constructive method to enhance visual quality of low light images. Illumination map estimation is the key factor to get good visual quality of low light image. We have designed an algorithm which will enhance the image with minimal computation time and require less energy which is suitable for wireless multimedia sensor networks. The experiment results have evident that our method is far superior than existing methods. It is positive that our method can be applied to many vision related application, wireless multimedia sensor network where visual quality is a major concern.

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