Color Image Enhancement Using Multiscale Retinex Based on Particle Swarm Optimization Method

F Matin1,*, Y Jeong1, K Kim2 and K Park1
1 School of Electronics and Engineering, Kyungpook National University, Daegu, South Korea
2 Etri, Electronics and Telecommunications Research Institute, South Korea

*E-mail: matin.academic@gmail.com

Abstract. This paper introduces a novel method for the image enhancement using multiscale retinex and practical swarm optimization. Multiscale retinex is widely used image enhancement technique which intertemporately pertains on parameters such as Gaussian scales, gain and offset, etc. To achieve the privileged effect, the parameters need to be tuned manually according to the image. In order to handle this matter, a developed retinex algorithm based on PSO has been used. The PSO method adjusted the parameters for multiscale retinex with chromaticity preservation (MSRCP) attains better outcome to compare with other existing methods. The experimental result indicates that the proposed algorithm is an efficient one and not only provides true color loyalty in low light conditions but also avoid color distortion at the same time.

1. Introduction
Image and video captured in different lights conditions like low brightness and various weather climates always result in unfavorable illumination. Moreover, it can proceed to lose significant details and information from the captured image. The propose of color image enhancement which is an unavoidable part of digital image processing [1] is to modify interpretability and perception of details in an image to prepare improved input for computer machines or human vision system. Image and video enhancement have turned into important research area owing to the prevalent use of the color image in many applications. Many image enhancement techniques in particular histogram equalization [2], gamma correction [3], homomorphic filtering [4], filtering intensity transformation [5] were designed to get distinguished details of an image which is not visible resulting from different lighting conditions. The most challenging part of image enhancement is to tune the parameters and lack of unified algorithms. In other words, when it comes to human vision system there is no quantitative standard theory to determining what an acceptable enhanced image is to human perception. Vast majority of the image enhancement algorithms focus on the input image rather than accommodate local aspects and also the image parameters need manual tuning in order to achieve an acceptable result [6]. Retinex is a nonlinear image enhancement algorithm that simulates the human visual system. The retinex algorithm has color constancy, high dynamic range and also it can sharpen the detail [7]. In this study Particle Swarm Optimization (PSO) is used to optimize the parameters of retinex image enhancement. The proposed algorithm performance has been measured with standard images, and the result compares with other retinex based algorithms. In the following section, introduce the basic
theory of retinex and PSO. In section 3 the proposed method (PSO-MSRCP) has been described, in detail. The experiment result and conclusion are represented in section 4 and section 5 respectively.

2. Theory of Retinex and Particle Swarm Optimization

Edwin Land and McCann introduced the retinex theory to model the human visual system [8]. The retinex theory has seen various development and alteration by many researchers. More specifically, multiscale retinex with chromaticity preservation [9] prepare satisfactory result which can be used in image processing. Although, the primary challenge with the retinex algorithm is selecting the values of the parameter such as Gaussian scales, gain and offset, etc. These parameters require being adjusted in order to procure reasonable effect. The principal purpose of the proposed method is to obtain the optimal values of the parameters which used in MSRCP algorithm via utilizing the optimization algorithm PSO. The proposed method (PSO-MSRCP) improves greater administration to compare with other retinex algorithms.

2.1. Multiscale Retinex Algorithm

Jobson et al. [10] developed Single-scale Retinex (SSR), Multiscale Retinex (MSR) and Multiscale Retinex with color (MSRCR) based on Land’s retinex. SSR is a center-surrounded algorithm. In the center-surrounded algorithm, the illumination is considered by the difference between the input value (center) and an average of its neighborhood. The formula of SSR can be represented as equation (1).

\[
R_i(x,y) = \log I_i(x,y) - \log C
\]

where \(R_i(x,y)\) is the retinex output image for the channel \(i^{th}\), \(x\) and \(y\) specified the coordinates of a pixel in image, \(I \in \{R, G, B\}\), \(I_i(x,y)\) is the image pixel value on the \(i^{th}\) color channel, \(C = F(x,y) * I_i(x,y)\), the symbol * indicates convolution and \(F(x,y)\) is Gaussian surrounded function. The convolution \([F(x,y) * I_i(x,y)]\) operation depicts the \(i^{th}\) of each color channel. Dynamic range compression and tonal range can provide by SSR simultaneously. But the result seems unnatural. To address this problem SSR extend to MSR. MSR can provide acceptable exchange between color rendition and dynamic range compression. The MSR output is specified as a weighted sum of various different SSR outputs.

The formula of MSR can be express as equation (2).

\[
R_{MSR_i} = \sum_{n=1}^{N} \omega_n R_{n_i} = \sum_{n=1}^{N} \omega_n [\log I_i(x,y) - \log [F_n(x,y) * I_i(x,y)]]
\]

where \(n\) is the scales numbers, \(\omega_n\) is each scale weight, \(R_{n_i}\) is the SSR output of the \(i^{th}\) component of the \(n^{th}\) and \(F_n(x,y) = C_n \exp \left[\frac{- (x^2 + y^2)}{2\sigma_n^2}\right]\). The MSR output is multiplying by a color restoration function. Mathematically the MSRCR restoration is described by equation (3).

\[
R_{MSRCR_i}(x,y) = C_i(x,y) R_{MSR_i}(x,y)
\]

where \(C_i(x,y) = f(I_i(x,y))\) is the \(i^{th}\) band color of restoration function (CRF). Jobson et al. [9] provided the finest general color restoration is defined by equation (4).

\[
C_i(x,y) = \beta \log \left[\alpha I_i(x,y)\right]
\]

where \(\beta\) is a gain constant and the nonlinearity strength can be controlled by \(\alpha\).

The final formula of MSRCR is described by equation (5).

\[
R_{MSRCR_i}(x,y) = G_i[R_{MSRCR_i}(x,y) - b]
\]
where the $G$ is the gain value and $b$ is offset value.

2.2. Particle Swarm Optimization

Particle swarm optimization is an evolutionary computational algorithm [11] was developed by Kennedy and Eberhart in 1995. The PSO is an initiative inspired algorithm which imitates bird’s social behavior and fish schooling that optimize a problem by iteratively trying to improve a candidate solution concerning given measure of quality. In this algorithm every potential solution known as a particle and every particle through the random search space according to the set of rules for a given random velocity. Each particle tracks the prior best position $P_{best}$ and its equivalent fitness. In the swarm, there will be many $P_{best}$ particles, and the particle with the greatest fitness know as a $G_{best}$ which is the best global in the swarm and guide the movement. The basic concept of PSO algorithm is to contribute to $P_{best}$ and $G_{best}$ for each particle. This process is repeated until a satisfactory solution discovered [6]. The particle updates its velocity and position after detecting best values of $P_{best}$ and $G_{best}$by follow equation (6) and (7).

\begin{equation}
  v_i(t + 1) = \omega v_i(t) + c_1 r_1 (p_i(t) - x_i(t)) + c_2 r_2 (g(t) - x_i(t))
\end{equation}

\begin{equation}
  x_i(t + 1) = x_i(t) + v_i(t + 1)
\end{equation}

where $x_i(t)$ illustrates position and $v_i(t)$ demonstrate velocity of the particle $i$ at time representative, $\omega$ is inter used to gained balance between global and local search, $c_1$ and $c_2$ are positive acceleration constants, and $r_1$ and $r_2$ are random values is the range of $[0,1]$. $p_i(t)$ is the best solution of the $i^{th}$ particle and $g(t)$ is the global best solution. In equation (6) in the first stage demonstrates the inertia velocity of the particle, in the second stage, represents the decision of the particle which made by its own experience and in the third stage shows the swarm’s experience.

3. Proposed Method

In this section multiscale retinex with chromaticity preservation [9] based on particle swarm optimization is presented. The color restoration block in the retinex algorithm (MSRCR) is at risk of inverting color. Color inversion can be observed in image pixels with about 0 values, which may jump to 255 or image pixels with about 255 values may drop to 0. This issue followed by color saturation in the image. To address this problem one of the solutions is to delete the color restoration part. However, eliminating the color restoration part turn the image in to grayish. In Particular, each image pixel is compared to the average of neighbourhood pixels and the difference is kept. In the result, the output can be grayish. A possible settlement to this problem is to use multiscale retinex on the intensity channel which results in the chromatically become identical to the input image. In the intensity channel $I = \frac{\sum_{i=1}^{s} I_i}{s}$, where $s$ shows the number of channels, apply to the MSR formula and for stretching the result to $[0,255]$ that is appropriate to concerning good image a linear transformation enforce to intensity output. MSRCP can define by equation (8) and (9).

\begin{equation}
  MSR = [1/3(\log(I_R + I_B + I_G) - \log(I_R + I_B + I_G) \ast G_{\sigma})]
\end{equation}

\begin{equation}
  F_{MSRCP} = \min \left( \frac{255}{\max(I_{R(0)}I_{B(0)}I_{G(0)})}, \frac{\text{int}_1(0)}{\text{int}(0)} \right)
\end{equation}

where $I$ is the input image, $\sigma_1$ is the scales, $G$ is the Gaussian, $\text{int}_1$ is simplest color balance (MSR, $s_1$, $s_2$) and $s_i$ is the percentage of clipping pixel on each side. In the final formula gain and offset are added to obtain an enhanced image following equation (10).
3.1. Objective Function

To measure the quality of an enhancement image automatically and without human intermediation, it is preferable to use an objective function [12]. The objective function is shown by equation (11).

\[ F(I_e) = \log \left( \log \left( E(I_e) \right) \right) \times \frac{n_{edges(I_e)}}{M \times N} \times H(I_e) \]  

(11)

where \( F(I_e) \) is the fitness function, \( I_e \) is the enhanced image equivalent to \( g(x,y) \), \( E(I_e) \) illustrates the sum of \( M \times N \) pixel intensities of Sobel edge image, \( n_{edges}(I_e) \) represents the number of pixels, whose the intensity value is above a threshold in the Sobel edge image. \( H(I_e) \) is the entropy value which is based on the histogram, computed on the enhanced image as equation (12).

\[ H(I_e) = \sum_{i=0}^{255} e_i \quad \text{where} \quad e_i = \begin{cases} h_i \log_2, & \text{if } h_i \neq 0 \\ 0, & \text{otherwise.} \end{cases} \]  

(12)

And \( h_i \) is the probability of occurrence of the \( x^{th} \) intensity value of enhanced image \( (I_e) \) between 0 to 255, shadows grey level in input image.

The multiscale retinex parameters in particular number of Gaussian scales \( \sigma_1, \sigma_2, \sigma_3 \), gain \( G \), offset \( b \), percentage of clipping pixels on the left and right side (simplest color balance) optimized with PSO. For each particle, the number of particles \( P \) valued 30, the number of dimension \( d \) set to 7 and number of iteration instated 30 to realize pleasant result. The range of parameters suggested for proposed method are as follows: Gaussian scale \( \sigma_1 \) [0, 50], \( \sigma_2 \) [51, 100], \( \sigma_3 \) [101, 255], gain [0, 30], offset [-15, 15] and percentage of clipping pixel are set with [1, 5] for both side respectively. The parameters choose for NASA’s MSRCR are \( \alpha \) [100, 150] \( G \) [150, 200], \( \beta \) [0, 25] respectively. The steps required in the optimization of above parameters are as follows:

**Step1:** Initialize \( P \) number of particles with dimension \( d \).

**Step2:** The particle position and corresponding velocity for \( \sigma_1, \sigma_2, \sigma_3 \), gain, offset and color balance saturation is randomly initialized within their range.

**Step3:** The number of iterations is initialized.

**Step4:** The enhanced image is obtained for every particle using equation (10).

**Step5:** The fitness value of every particle is computed using equation (11).

**Step6:** The fitness values of every particle is compared with its \( P_{best} \) value; if fitness value of particle is better than \( P_{best} \), then it becomes the \( P_{best} \).

**Step7:** Next, the fitness values of every particle are compared with the ‘\( G_{best} \)’ value; if fitness value of particle is better than ‘\( G_{best} \)’, then it becomes the ‘\( G_{best} \)’.

**Step8:** The particle’s velocity and position are updated using equation (6) and (7).

**Step9:** If the number of iterations is less than the chosen, steps from 4 to 8 are repeated. Otherwise, the algorithm is terminated.

4. Experimental Result and Analysis

This section presents the experimental result to appraise the performance of the proposed method with a number of standard image enhancement techniques in particular, MSRCR [7] and NASA’s MSRCR [10]. The input images resolution resize to 512×336 in order to reduce the operation time. The proposed method was coded and verified using C++. Several experiments were presented by considering many test images with poor quality. To illustrate the result of proposed method two different images are shown in Figure 1 and 2. Figure 1(a) and Figure 2(a) show the input images. In Figure 1(a) the background of the image is pretty dark, and the details of the picture are not visible. In Figure 2(a) the face of the girl and the reflection in the car window have bad quality and hardly
noticeable. The image enhancement MSRCR used in Figure 1(b) and Figure 2(b) as a result the contrast of the images are improved, and the backgrounds parts of both images are more visible, but images suffer from the color distortion. In Figure 1(c) and Figure 2(c) NASA’s MSRCR applied to the images and the result is far better compared to MSRCR. In Figure 1(c) the details about the clothes of the first person and her face are not clear. In Figure 2(c) the reflection in the windows of the car and the eyes of the girl are over enhanced and barely visible. Figure 1(d) and Figure 2(d) show the results of enhanced images by the proposed method MSRCP based PSO. In Figure 1(d) most of the details, in addition, the clothes of the first person, the water color and the background of the image all improved much better compared with NASA’s MSRCR. In Figure 2(d) the enhanced image preserves the contrast and the sharpness of the image. Moreover, the girl eyes, the reflection in the windows of the car and the trees and sky in the background are suitably enhanced compared to other methods.

The Table 1 shows the proposed method parameters acquired the test images optimized with PSO.

### Table 1. Optimized parameters of MSRCP by using PSO

| Image  | Low scale [0,50] | Medium scale [51,100] | High scale [101,255] | Gain [0,30] | Offset [-15,15] | color balance left [1-5] | color balance right [1-5] |
|--------|-----------------|----------------------|----------------------|-------------|-----------------|--------------------------|---------------------------|
| Girl   | 46              | 57                   | 134                  | 19          | 1               | 1.6                      | 1.8                       |
| Boat   | 14              | 97                   | 194                  | 21          | 8               | 1.4                      | 1.5                       |

**Figure 1.** Boat image and enhancement result: (a) input image. (b) MSRCR. (d) NASA’s MSRCR. (e) result of the proposed method.

**Figure 2.** Girl image and enhancement result: (a) input image. (b) MSRCR. (c) NASA’s MSRCR. (d) result of the proposed method.

In order to evaluate the efficiency of the proposed method, it compared with other methods based on histogram plot, luminance enhancement performance, and contrast enhancement performance. Table 1 and 2 shows the contrast and luminance values of Figure 1 and 2 respectively. It is clear that the luminance value of the enhanced image with the proposed method determined 55% or greater details. Besides proposed method performance offers a balance between luminance and contrast compare to MSRCR and NASA’s MSRCR.

Histogram plot obtained by the input image, MSRCR, NASA’S MSRCR and proposed method are shown in corresponding images from Figure 3(a)-3(d) to Figure 4(a)-4(d) respectively. Based on histogram plot proposed method offers better pixel distribution, dynamic range of color and balance between contrast and luminance compare to MSRCR and NASA’s MSRCR.
Table 2. Performance of Figure 1

| Boat Image | Input Image | MSRCR | NASA’s MSRCR | Proposed method |
|-----------|-------------|-------|---------------|-----------------|
| **Luminance** | 0.546 | 1.130 | 1.066 | 1.331 |
| **Contrast** | 0.352 | 0.640 | 0.682 | 0.664 |

Figure 3. Histogram plot of boat image: (a) input image. (b) MSRCR. (d) NASA’s MSRCR. (e) result of the proposed method.

Table 3. Performance of Figure 2

| Girl Image | Input Image | MSRCR | NASA’s MSRCR | Proposed method |
|------------|-------------|-------|---------------|-----------------|
| **Luminance** | 0.649 | 0.884 | 0.746 | 1.183 |
| **Contrast** | 0.714 | 0.731 | 0.786 | 0.710 |

Figure 4. Histogram plot of girl image: (a) input image. (b) MSRCR. (c) NASA’s MSRCR. (d) result of the proposed method.

5. Conclusion

In this paper a novel method for the image enhancement using multiscale retinex and practical swarm optimization has been introduced. An efficient, objective function rooted at edge and entropy information of an image has been used in this work to measure the quality of a provided image. The retinex parameters such as Gaussian scales are optimized by PSO to achieve the best exist parameters for image enhancement. The proposed method results compare to standard and existing methods which used the retinex algorithm, improve quality of the color image and achieve high performance in both color quality and clarification. The image captured in different lights conditions and various weather climates can be enhanced by presented method.

Acknowledgments

This study was supported by the BK21 Plus project funded by the Ministry of Education, Korea (21A20131600011).

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