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Aerial Images Enhancement Using Perceptual Dark Channel Prior

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Abstract: Improvements in aerial images have an important role, given the increase in dust storms due to global warming and climatic changes. Apart from improving aerial images, image enhancement is important in many applications, such as tracking and monitoring studies during wars and for the environment. However, aerial images often suffer from a lack of contrast due to dust and pollutants. In this study, we propose a perceptual dark channel prior (PDCP). In this method, the light value (Y) is improved by using stretch and perceptual color space, and then the chromatic compounds (CbCr) are improved by dark channel prior (DCP). The quality measures lightness order error (LOE), entropy, and color-fullness metrics (CM) and then compares these with the improved methods (DCPMV, YCBCR, MLA, SEA, DCP, and IEIF) to determine the method efficiency. Results show that the proposed PDCP effectively enhances the aerial images better than other methods, because owning it the average are LOE (194.096), EN (7.361), and CM (39.403).

Keywords: Aerial image, Dark channel prior, Image stretch, Lightness order error, YCbCr color space.

1. Introduction

Image processing is concerned with performing operations on images for improvement according to specific criteria or for extraction of specific information [1][2]. Images, such as dusty ones, commonly suffer from a decrease in light and contrast [3]; however, such a decrease plays an important role in aerial images. The aerial image is a photographic process carried out from the air, often by using air transports [4]. Aerial images present information on the following: the surface of the earth and its events, as well as the effect of erosion from cutting forests and mountains; archaeological sites; agricultural lands and large pastures, and which ones to be distributed to the public; and natural disasters, for their study and prevention [5]. Kareem et al. proposed an algorithm for improving a group of aerial photographs that suffer from the haze. Four aerial images of type JPG were selected by relying on the YCbCr color space with the use of a composed sigmoid function [6], this the method succeeded in improving the aerial images after using entropy and average gradient, but, this the method is not successful in retrieving the color information. Jonathan et al proposed an algorithm to improve dark images and convert them into a light scene through perceptual color transfer; with adjustments in hue, surfaces, and contrast, the study succeeded in processing techniques with a night or low-light vision. The best results are obtained from color transfer in RGB and depended on color transfer applied to images in RLAB [7]. Ameer et al. used an algorithm of histogram equalization based on color restoration to improve underwater images. The method depends on the images in RGB color space and then color correction by using (XYZ, and LMS) color spaces. The best results are obtained in improving both lighting and contrast in low-quality underwater images [8], the same retrieval concepts are used in [9]. Rajesh et al. proposed an image optimization algorithm and a cleaning technique for underwater mining, which relies on performing colour correction on the images merged with DCP, the converted images are then adjusted into the long, medium, and short (LMS) colour space, thereby providing the best results for contrast and natural appearance in optimization methods for underwater images [10]. Ngo et al. used an algorithm to obtain a clear image from images degraded by haze, snow, or yellow dust. According to the machine learning approach (MLA) technology, the accelerator has a capacity of 4K. The algorithm improved the color attenuation and enhanced the effectiveness and reliability of the training dataset, resolving constraints of the transmission map, with a resolution for background noise, adaptive tone, and color distortion. Using the hardware accelerator method, the general architecture is considered, and the network-based optimized sorting of a dual-modulated medium filter, atmospheric light, compensation, and hardware validation are estimated[11], this algorithm gives a fairly good contrast, but it does not provide an improvement in color information, in addition to the large error in the returned lightness. Park et al suggested a method that includes Image entropy and information fidelity (IEIF) to enhance hazy images, in this algorithm the atmospheric light was estimated by quadtree subdivision, and the transmission is circulated using objective function biased entropy fidelity [12], one of the advantages of this method is that it preserves the original lighting information, but it does not give a high improvement to the color information. Raanan Fattal suggested a method to estimate the (optical) transmission in scenes with fog inside the image (single entry). Based on the estimation, the visibility of the scene is increased when distracting light is eliminated and the contrast is restored for haze-free scenes.

The refined image formation model is formulated in this approach and is responsible for the surface transport function in addition to surface shading. The model helps resolve uncertainties in the data by searching for a solution in which the resulting transmission and shading functions are related based on local statistics, this method demonstrates capabilities for haze layer removal and provides a reliable transmission estimation that can be used in other applications such as new rendering tuning and image refocusing [13]. J. Tarel and N. Hautière aimed to restore vision with a single image without using any additional information as a specific filtering problem. They proposed an algorithm based on an averaging filter, a linear function of the input size image, such that the main advantage is its speed, and at the same time, obtains more favorable results compared with sophisticated algorithms. The study also introduced a new filter that keeps the boundary at an obtuse angle as an alternative to the averaging filter, but other operators for restoring a view that allows an understanding of the atmospheric veil can also be imagined. Therefore, due to its speed, the proposed algorithm can be used with benefits such as pre-processing in many systems involving smart vehicles, monitoring, and remote sensing [14].

Before defogging a single input image, He et al provided an image that is not only simple but also effective before the dark channel, the best image quality without haze is maintained and the haze particle thickness is accurately estimated. The strength of the former suggestion has been demonstrated by the results of various hazy images [15], it is one of the most important methods for improving hazy images and has a good ability to retrieve color information, but it does not increase contrast.

Galdran et al proposed a technique to remove image haze and eliminate optical degradation. The reason is that haze does not depend on the physical model of reflection of formation, and instead, the basic underlying assumptions are respected [16]. Fayaz et al introduced an algorithm depending on the scene estimation approach (SEA) to enhance areal images using RGB color model with color correction involving a Fourier transform [17], in this algorithm, they reached a good enhancement in color information for hazy images, but the contrast in those images was not good. Li et al present the haze image enhancement algorithm using dark channel prior algorithm in machine vision (DCPMV), this method includes DCP and MSRCR depending on HSV color space [18], from their result we can see this algorithm improves color information well but does not give good contrast improvement.

In this study, we propose the PDCP algorithm. In this method, the light value (Y) in the color conversion of YCbCr is improved by using Perceptual color space, and the chromatic compounds (CbCr) are improved by DCP, what distinguishes this method is its success in retrieving color information and increasing contrast while preserving the original lighting data

2. Suggested method

This study proposes an enhancement algorithm for aerial images based on the YCbCr color space, where the DCP algorithm is used to enhance the chromatic component (CbCr) and the lightness component is enhanced by stretch and Perceptual color space (LMS) as follows:

2.1 Improved chromatic compounds by DCP algorithm

The proposed method is based on the enhancement of aerial images using the YCbCr color space, where the DCP technique is used on CbCr color composites. The DCP algorithm is applied to the color image, which is subsequently converted to a YCbCr space and optimizing (CbCr) extraction. The general form describing dust or haze in a scene is given as follows [15]:

$$A\,(v) = I(\,v)\;tr(v) + \;Bc\;(\,1 - t_r(\,v)) \qquad (1)$$

where A is hazy image intensity and I is a radiance in a scene, Bc is the atmospheric light and t_r a transmission channel. The DCP technique is among the most important techniques that depend on solving the attenuation model, which is used to improve aerial or dusty images, and components of which DCP is known, Ii, the image is given by [15]:

$$I_{dark}(\,v) = min_{i\,\epsilon\,\{r,g,b\}}\,(min_{\,y\epsilon\,R\,(v)}\,\left(Ii\,(y)\right)) \qquad (2)$$

where Ii denotes three channels (red, green, and blue) of i and $R(v)$ is the local patch with v center coordinate. By using a DCP technique, the intensity of the dark channel of Ii is low and becomes zero, where Ji is an outdoor haze-free (without haze) image except the bright area obtained by:

$$I_{dark}(\,v) \cong 0 \qquad (3)$$

Thus, the transmission component value can be given by [15]:

$$t_r\,(v) = 1 - d_{\,miny\epsilon\,R(v)}\left(\,min_{i\,\epsilon\,\{r,g,b\}}\,\frac{J(y)}{Bc}\right) \quad (4)$$

Soft mapping can be used to refine a transmission. If the dust or haze is removed, the image becomes unnatural, and thus the value$(0\; < d < 1)$, d is set at 0.95 and atmospheric light (optimal value) are $= 0.1$, with patch size (15×15). Subsequently, the enhancement image is given by [15]:

$$I(v) = \frac{J(v) - Bc}{max\;(t_r(v),0.1\;)} + \;Bc \qquad (5)$$

The DCP one color space technology based on the human visual system is the YCbCr color space. The image that is enhanced using the DCP algorithm can be converted from the basic $R\,,B\,,G$ space to YCbCr space, and then only the saturation and color of the hue compounds (CbCr) are retained by using transformation [19]:

$$\left.\begin{aligned} Y\; &= 0.298R + 0.587G + 0.114B \\ Cb &= 0.169R - 0.331G + 0.500B \\ Cr &= 0.500R - 0.418G - 0.081B \end{aligned}\right\} \qquad (6)$$

2.2 Lightness enhancement using perceptual colour space

The image stretch for a hazy image $C(x,y,i), i = 1,2,3$ (red, green, and blue) channels, is implemented to enhance the image. This enhance is depending on the standard deviation and mean value of the RGB channels calculated by [9]:

$$d_{\,max,i} = d_{\,mean,i} + kd_{\,std,i} \qquad (7)$$

$$d_{min,i} = d_{mean,i} - kd_{\,std,i} \qquad (8)$$

$d_{\,mean,i}$ and $d_{\,std,i}$ are the average value and the standard deviation of the lightness component, respectively; k is a constant for controlling dynamic histograms; and $d_{\,max,i}$, $d_{\,min,i}$ are the maximum and minimum of (i) components, respectively. The image enhancement is obtained by image stretch as follows [9]:

$$I_{s,i} = \frac{I_{\,i} - d_{\,min,i}}{d_{\,max,i} - d_{\,min,i}} \times 255 \qquad (9)$$

The LMS is a color space represented by the response of the three types of cones of the human eye, named for their responsively (sensitivity) peaks at long, medium, and short wavelengths. The dehazed image is now converted to the XYZ color space and multiplied to a chromatic adaptation matrix in the Von Kries transform method, however, this expects the LMS color space. First, the transform from basic color space RGB to XYZ is given by [19]:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} 0.6326 & 0.2045 & 0.1269 \\ 0.2284 & 0.7373 & 0.0341 \\ 0.0000 & 0.0095 & 0.8156 \end{bmatrix} \begin{bmatrix} r \\ g \\ b \end{bmatrix} \qquad (10)$$

The relationship between the XYZ and LMS color spaces is linear, so the transition is represented by a transformation matrix [8]:

$$\begin{bmatrix} l \\ m \\ s \end{bmatrix} = \begin{bmatrix} 0.389 & 0.688 & -0.078 \\ -0.229 & 1.183 & 0.046 \\ 0.000 & 0.000 & 1.000 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} \qquad (11)$$

This transition produces the final image. In several cases, a simple color balance may be added to retain the color of the image or bring back certain colors. This step also allows for saturation of the image within specified parameters. Then we used Eq. (6) to transform to YCbCr color space and estimate the lightness component (Yp). Next, a reverse conversion is carried out from YCbCr to RGB. The conversion is given by [19]:

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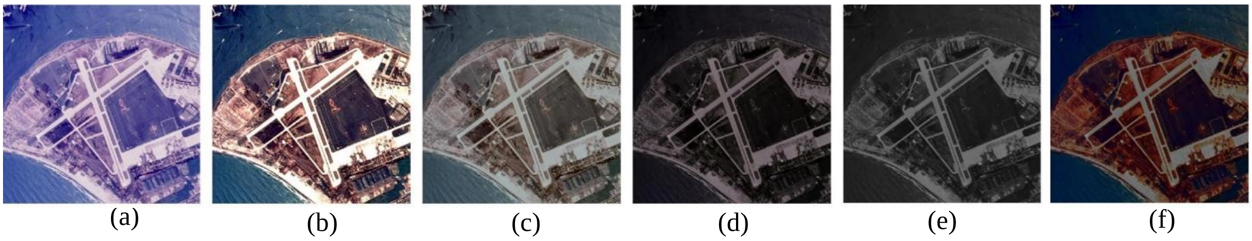

Figure. 1 Important stages of the proposed algorithm: (a) Original aerial image, (b) DCP enhancement, (c) stretch for the original image, (d) LMS color space, (e) Y-component from LMS color space, and (f) Final enhancement

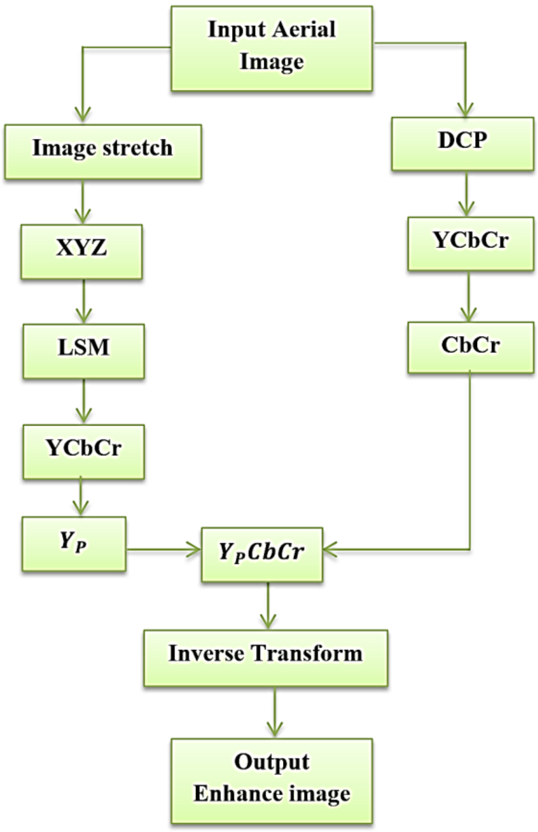

Figure. 2 Scheme of the proposed algorithm.

$$\begin{aligned} R &= \mathrm{Yp} + 1.401cr \\ G &= \mathrm{Yp} - 0.343cb - 0.713cr \\ B &= \mathrm{Yp} + 1.772cb \end{aligned} \qquad (12)$$

Then, the chromatic compounds (cr and cb) are enhanced by using DCP and the illumination (Yp) is enhanced using the adaptive graph equation by the sigmoid function.

3. Quality measures

Entropy is used to measure the amount of contrast and detail in an image. The higher its value, the higher the contrast and it's given by [21]:

$$EN\ (I) = -\sum_{i=0}^{l-1} p(I)\, logp(I) \qquad (13)$$

Where $p(\mathrm{I})$ is the histogram of intensity. The Lightness Order Error (LOE) between the original image I and process image *Ip*. The LOE is depending on [22] :

$$L(x,y) = \max_{i \in \{RGB\}} Ii(x,y) \qquad (14)$$

The order difference of the lightness is Calculates from:

$$RDiff = \sum_{i=1}^{m} \sum_{j=1}^{n} (U(L(x,y), L(i,j)) \oplus U(L_p\,(x,y), L_p(i,j))$$

$$U(x,y) = \begin{cases} 1 & for\ x \geq y \\ 0 & else \end{cases} \qquad (15)$$

m And n is the height and the width, $U(x,y)$ is the unit step function, $\oplus$ is the exclusive-or operator. And then:

$$LOE = \frac{1}{m*n} \sum_{i=1}^{m} \sum_{j=1}^{n} RDiff\ (i,j) \qquad (16)$$

The Color-fullness Metrics (CM), called Chromatins is the attribute of a visual sensation, and it is Measures the amount of color detail by using CIELAB color space as [23]:

$$CM = \sigma_{AB} + 0.94\mu_c \qquad (17)$$

$$\text{And, } \sigma_{AB} = \sqrt{(\sigma_A)^2 + (\sigma_B)^2} \qquad (18)$$

Where σ_{AB} is the trigonometric length of the standard deviation in A and B components and μ_c is the mean of the chroma component.

4. Results and discussion

In this study, the aerial images are enhanced using USC-SIPI data [20] that consist of (36) aerial images with size 512×512 in JPG format, as shown in Fig. 3. Matlab R2020a program is used to perform all

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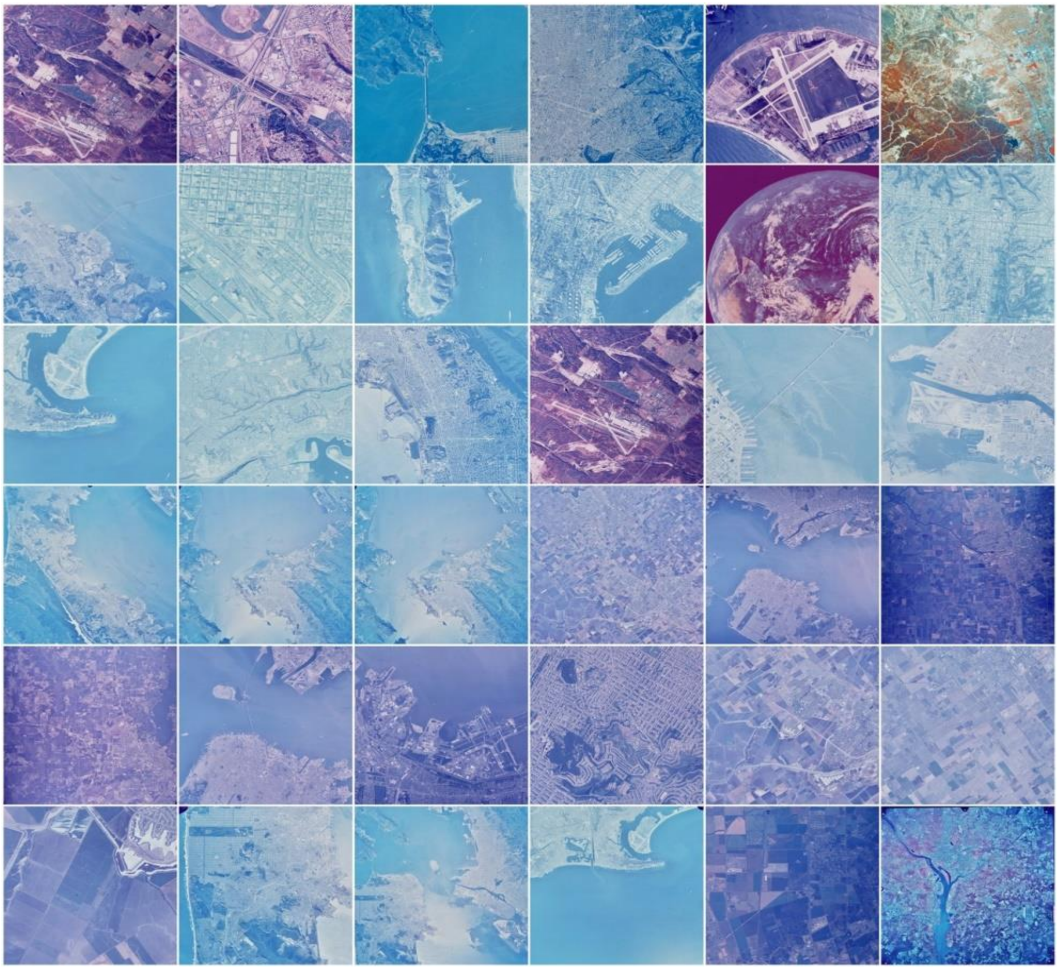

Figure. 3 Data set of the aerial images [20]

Table 1. Average of enhanced quality aerial images

Method	LOE	EN	CM
PDCP	**194.096**	7.361	39.403
DCPMV[18]	405.610	6.877	**41.655**
YCbCr[6]	505.440	**7.506**	39.141
MLA[11]	382.471	6.507	35.4
SEA[17]	449.062	7.353	19.125
DCP[15]	337.662	7.338	39.716
IEIF[12]	261.027	7.222	39.39

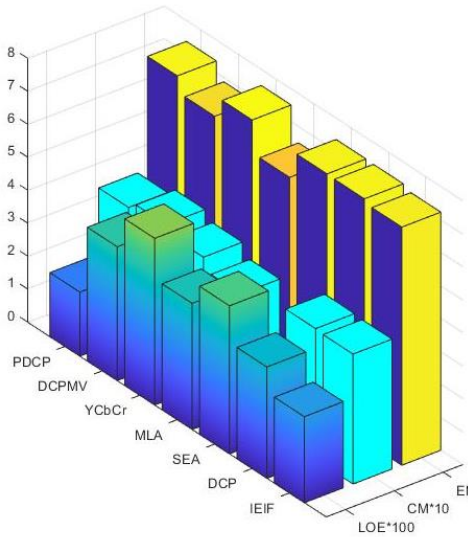

Figure. 4 3D bar plot for Table 1

enhancement algorithms. To determine all the enhancements of the proposed method, we use three quality measures of LOE, EN, and CM, and compare them with several algorithms (PDCP, DCPMV, YCBCR, MLA, SEA, DCP, and IEIF). Table 1 presents the average quality of the enhanced aerial images. The proposed method shows the least lightness error after enhancing to scale LOE and is followed by IEIF. This result indicates the success of the proposed method in improving and restoring colors while preserving the original lightness component. The measure of entropy represents the degree of contrast, and the best results are obtained by YCBCR and the proposed method. As for measurements, PDCP notes that the best methods are DCP and DCPMV. This result indicates the success of the method in retrieving chromaticity details.

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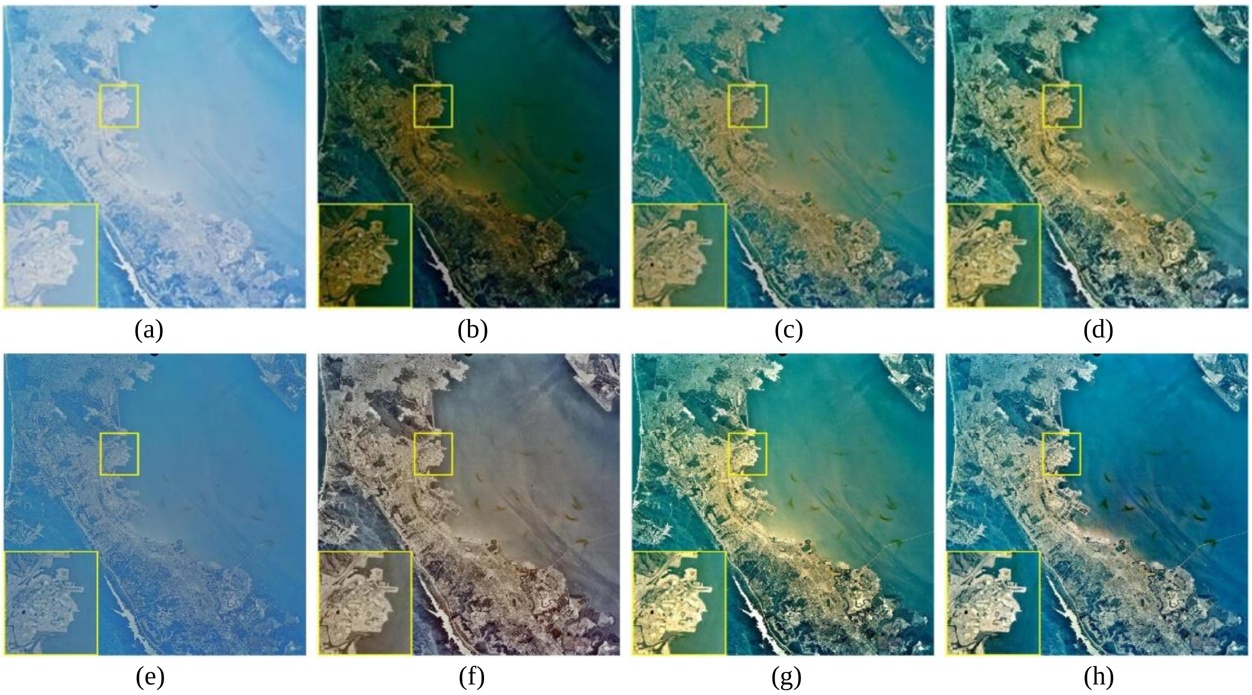

Figure. 5 Magnified area of an aerial image with label 4 in: (a) Original image, enhanced using different algorithms, (b) PDCP, (c) DCPMV, (d) YCbCr, (e) MLA, (f) SEA, (g) DCP, and (h) IEIF

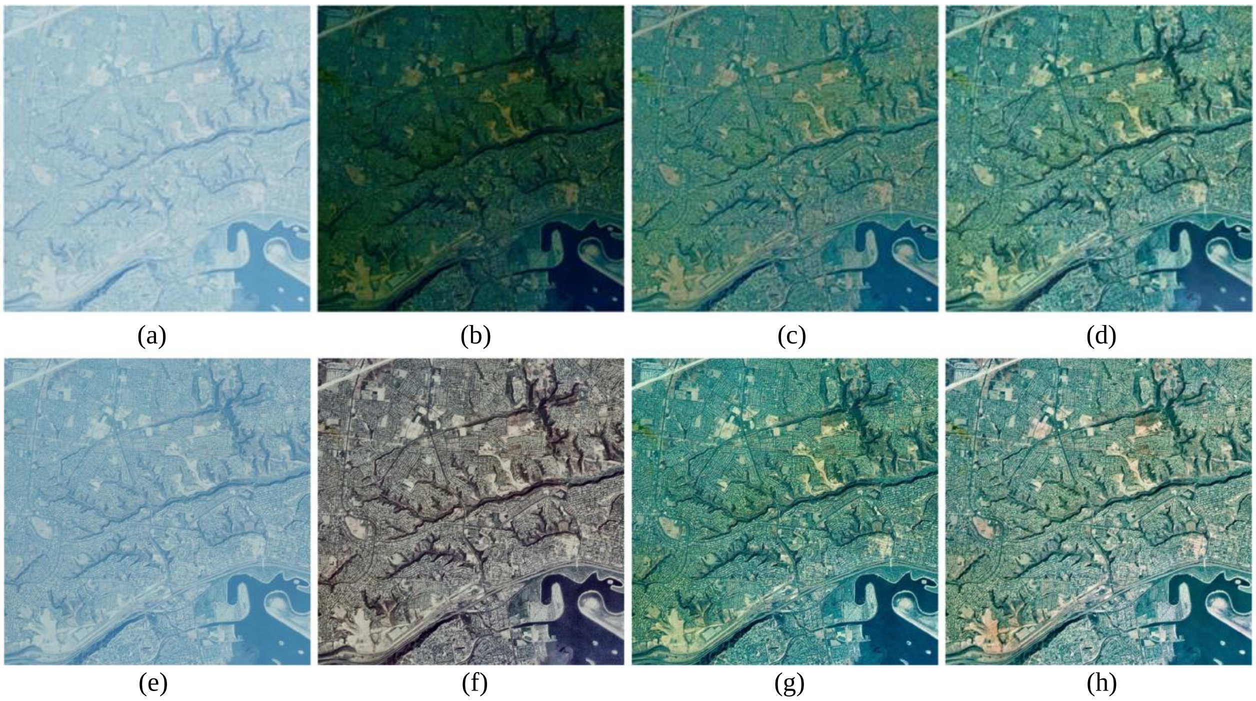

Figure. 6 Aerial image with label 35 in: (a) Original image, enhanced using different algorithms, (b) PDCP, (c) DCPMV, (d) YCbCr, (e) MLA, (f) SEA, (g) DCP, and (h) IEIF

Fig. 4 represents the Table 1 results in a 3D bar plot. Fig. 5 represents a magnified area of a part of an image with high contrast and clear color details compared with the rest of the methods. Fig. 6 shows an image chosen to see the distribution of histograms for all methods. In Fig. 7, we note the success of the proposed method in obtaining the best ranges for compounds RGB as they became wider.

5. Conclusions

In this study, aerial images with low contrast are improved using the proposed method PDCP. Compared with other methods (DCPMV, YCbCr, MLA, SEA, DCP, and IEIF) by using quality metrics, the results average are LOE (194.096), EN (7.361), and CM (39.403) for the proposed method. Thus,

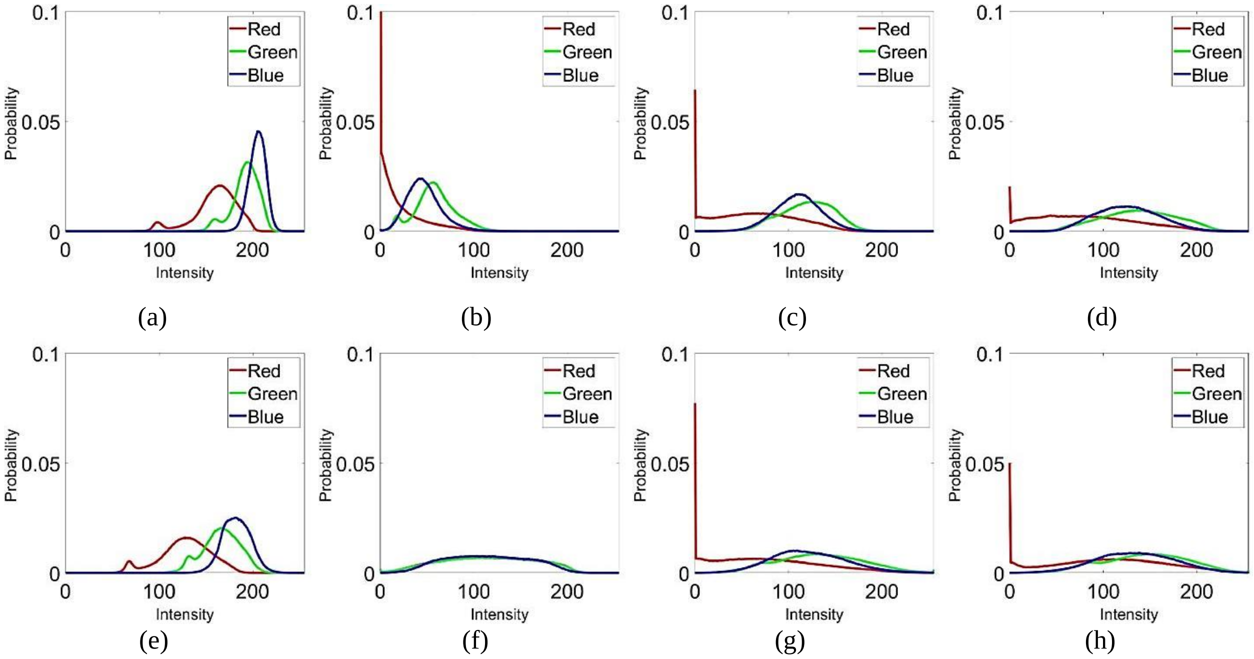

Figure. 7 Histogram of the aerial image with label 35 in: (a) Original image, enhanced using different algorithms, (b) PDCP, (c) DCPMV, (d) YCbCr, (e) MLA, (f) SEA, (g) DCP, and (h) IEIF

PDCP effectively improves aerial images. This result indicates the algorithm success to retrieve color information better than the other methods. In the future, the proposed algorithm can also be used to enhance underwater images.

Conflicts of interest

No conflict of interest.

Author contributions

Nadia A. Khalaf has contributed to the design and implementation of the research by using Matlab. Hazim G. Daway and Baida M Ahmed supervised the written paper and provided the necessary data. All authors approved the final version.

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A notation list

Symbol	Abbreviation
$A(v)$	Hazy image intensity with v center coordinate
Bc	Atmospheric light
b	Blue component in basic color space
CM	Color-fullness Metrics
Cb	Chromatic component in YCbCr
Cr	Chromatic component in YCbCr
d	Constant
$d_{mean,i}$	average of ith channels
$d_{std,i}$	standard deviation of ith channels
EN	Entropy
g	Green component in basic color space
$I(v)$	Radiance with v center coordinate
I_{dark}	Dark channel of scene radiance
Ii	Three channels (red, green, and blue)
$I_{s,i}$	image stretch of ith channels
k	Constant
l	Long component in the Perceptual LMS color space
m	Medium component in the Perceptual LMS color space
$p(I)$	Histogram of intensity.
r	Red component in basic color space
$R(v)$	local patch with v center coordinate
s	Short component in the Perceptual LMS color space
$t_r(v)$	Transmission map with v center coordinate
x	Red component in XYZ space
y	Green component in XYZ space
Y	Lightness component in YCbCr
Yp	Processing Lightness component
z	Blue component in XYZ space
σ_{AB}	Trigometric length of the standard deviation
μ_c	mean of Chroma component