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# A Hybrid Processing Approach for Enhancement of MAV Aerial Images

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**Abstract**: This paper proposes a hybrid approach for the enhancement of aerial images obtained from UAV/MAV cameras. Aerial images are prone to many undesirable effects such as non-uniform lighting, turbidity due to haze and other atmospheric noise. The aim of the proposed scheme is to achieve the enhancement, where the existing techniques relying on Wavelet based Dynamic Range Compression (WDRC) algorithm followed by Local Contrast Enhancement (LCE) fails to achieve desired results. The processing involves both spatial and frequency domain operations which have been carried out through the implementation of post-processing techniques to those images which have still very poor contrast after the application of WDRC and LCE. The post processing techniques involve the use of histogram equalization, removal of noisy artifacts and Laplacian sharpening in a sequential order. The scheme was used for the enhancement of a series of aerial images obtained from MAV camera on flight. Images enhanced by the scheme are found to be of much better clarity and vividness, especially in the case of images acquired by MAV inbuilt cameras.

**Keywords**: Aerial image processing, Laplacian Sharpening, Local contrast enhancement Spatial/Frequency domains, Wavelet-based Dynamic Range Compression.

## I. INTRODUCTION

Unmanned Air Vehicles like UAVS and MAVs have small inbuilt cameras to take photographs (aerial images) for a number of civil and defence applications. Images taken during the flight from heights above 100m are subjected to various undesirable effects due to camera movement, non-uniform lighting conditions, turbidity, haze, fog, clouds etc. This not only causes a significant reduction in the clarity of such images, but the important details may be hidden under the noise that contaminates the image. It is thus obvious that the utility of these captured images, unless processed, is very limited.

Natural scenes have high dynamic range. Images captured by the cameras are often poor rendition of the natural scenes. Even though the human eyes have a lesser dynamic range, the biological system adjusts to it by dynamic range compression and adapting locally to each part of the scene. The low dynamic range of cameras results in the loss of contrast. There are many algorithms for dealing with problems regarding limited dynamic range like global histogram modification, logarithmic compression etc [1]. However, these methods alone contribute little to enhancement of the quality of images suffered from the above problems.

Considerable research work is under progress, on the processing of images obtained from Micro Air Vehicle (MAV), in vehicle detection, remote sensing, and correction of camera rolling. Manera et.al [2] presents a computational system which automatically processes optical and multispectral MAV images. The system includes image acquisition, rectification and image mosaicing. Bharati et.al [3] proposes a differential morphology closing profile for extracting vehicles automatically from traffic images, which includes image pre-processing, differential morphology profile, thresholding and filtering. A technique based on digital photogrammetric technique for large scaling mapping has been developed by Udin et al [4], which has advantages like low cost, faster and simplicity. A method for automatic generation of orthophoto mosaics using scale invariant feature transform (SIFT) for automatic key point detection and matching problems has been proposed by Marcus et.al in [5].

Many advanced methods have been developed to improve the local contrast of the images. E. Land's theory [6] has produced good results in dynamic range compression and color constancy while MSRCR (Multi-Scale Retinex with Color Restoration) [7] is a retinex based algorithm that uses logarithmic compression and spatial convolution. The main drawback of MSRCR is that the color restoration changes chromatics of the image in an undesirable manner. Adaptive and Integrated Neighborhood Dependent Approach for Nonlinear Enhancement (AINDANE) [8] is used for images taken under low illuminance condition, which includes adaptive luminance enhancement, adaptive contrast enhancement and color restoration. Locally Tuned Sine Non-Linear (LTSN) technique [9] is used for extremely high contrast images, which includes adaptive intensity enhancement, contrast enhancement and color restoration. A novel approach for removing illuminance effect on aerial images taken under non-uniform lightning condition is proposed Ansari and Arigela [10], where histogram adjustment and color restoration are used along with WDRC algorithm [1] to improve the visual quality. But this algorithm (Automatic WDRC) is not sufficient for images having very poor contrast. In the present work, we propose a post-processing step which improves the visual quality of those images with very poor contrast and eliminates noise from the images.

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The algorithm employs a hybrid approach, as it uses both spatial and frequency domain operations. Initially, the histogram of the image is adjusted to avoid the illuminance effect so as to deal with the strong spectral characteristics of the aerial images. Local contrast enhancement is used in the algorithm in order to restore and improve the contrast lost during dynamic range compression. A non-linear color restoration is then used to provide color constancy. In the post processing step, use of histogram equalization enhances the contrast of very low contrast images for which the approach of Ansari and Arigela [10] is inadequate. It may also be noted that the application of Gaussian and median filtering eliminates the noise in the images which occur while performing color restoration. Finally, Laplacian sharpening is employed to make the edges more clearly visible.

## II. METHODOLOGY

The proposed algorithm comprises mainly of the following modules.

- (A) Pre-processing
- (B) WDRC and LCE
  - (i) Wavelet based dynamic range compression
  - (ii) Local contrast enhancement
  - (iii) Detail coefficient modification
- (C) Color Restoration
- (D) Post processing
  - (i) Histogram Equalization
  - (ii) Removal of noise effect
  - (iii) Laplacian Sharpening

These modules are discussed in detail in the following subsections.

### *A. Pre-processing*

Histogram adjustment [10] is performed in the spatial domain to decrease the illuminance effect occurring due to non-uniform lightning conditions. This effect causes a linear shift (after assuming nonlinear properties of human visual system [11 and 12]) in the beginning of the lower tail of image histograms and may vary in different spectral bands. This linear shift can be observed in the histogram plotted in Figure 1 for a given image corrupted by atmospheric haze and turbidity along with noise. The shift due to illuminance effect is determined from the lower tails of the histogram in Figure 1(c), (e) and (g). For Channels R, G and B the corresponding shifts are 0.2275, 0.2353 and 0.2039. They are then subtracted from all pixel values of the respective channels to form adjusted histograms in Figure 1(d), (f) and (h). Figure 1(b) shows the corresponding histogram adjusted image.

### *B. WDRC and LCE*

WDRC is basically an algorithm to deal with the problems caused by the limited dynamic range of the imaging devices and to improve its visual quality. It has been modified in which is followed here.

(i) Wavelet-based dynamic range compression: This particular operation is performed on the intensity image in frequency domain. Intensity image is taken as the one with maximum value of the three color channels and is given by equation (1) as follows.

$$I(i,j) = \max\{I_m(i,j)\},\ m\epsilon[R,G,B] \tag{1}$$

where $I(i,j)$ is the intensity of the image at $(i,j)^{th}$ pixel location. The intensity image is then decomposed using orthonormal wavelet transform as shown in equation (2).

$$I(i,j) = \sum_{a,b\epsilon Z} p_{N,a,b}\Phi_{N,a,b}(i,j) + \sum_{n\geq N}\sum_{a,b\epsilon Z} q^h_{N,a,b}\Psi^h_{N,a,b}(i,j) + \sum_{n\geq N}\sum_{a,b\epsilon Z} q^v_{N,a,b}\Psi^v_{N,a,b}(i,j) + \sum_{n\geq N}\sum_{a,b\epsilon Z} q^h_{N,a,b}\Psi^h_{N,a,b}(i,j) \tag{2}$$

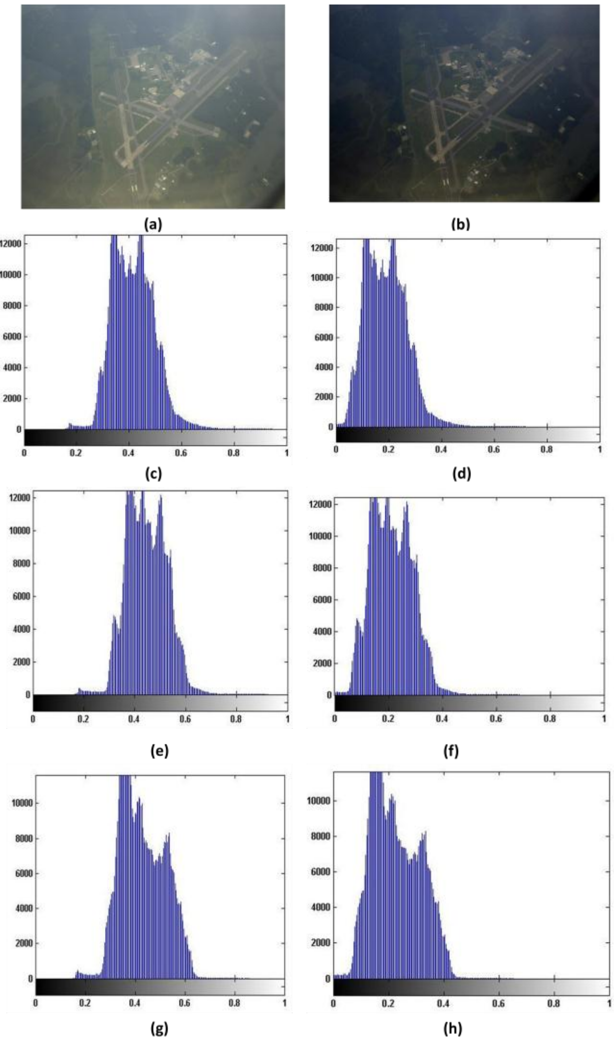


Figure 1: Histogram adjustment. (a) Input image, (b) Histogram adjusted image, (c),(e) & (g) Histograms of RGB channels of input image, (d),(f) & (h) Histograms of RGB channels of histogram adjusted image.

where $p_{N,a,b}$ are the approximation coefficients at scale $N$ with corresponding scaling function $\Phi_{N,a,b}(i,j)$ and $q^h_{N,a,b}$ are the detail coefficients with corresponding wavelet function $\Psi^h_{N,a,b}$.

A single level decomposition using Haar wavelet is employed here for better and low noise performance. This is followed by a scaling of the approximation coefficients by a two sided raised hyperbolic sine function which pulls up the smaller coefficients and pulls down the larger ones as performed in equation (3).

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$$\bar{p}_{N,a,b} = \left[\frac{\sinh(4.6248p'_{N,a,b} - 2.3124) + 5}{10}\right]^r \qquad (3)$$

Where

$$p'_{N,a,b} = \frac{1}{255}\frac{p_{N,a,b}}{2^N} \qquad (4)$$

Equation (4) gives the normalized coefficients and r is the curvature parameter which adjusts the shape of the hyperbolic sine function. Since the approximation coefficients indicate the dynamic range of the intensity, the scaling operation calls for the compression of dynamic range which in turn reduces the image contrast drastically. Hence it is required to employ a local contrast enhancement in order to preserve the contrast of the image.

(ii) Local contrast enhancement: The local contrast enhancement is done based on *centre surround* approach. Gaussian filter is used to extract the surrounding intensity information. As the first step, normalized approximation coefficients are filtered using Gaussian kernel given by equation (5)

$$H(i,j) = G\ exp\left(-\frac{i^2+j^2}{\sigma^2}\right) \qquad (5)$$

where $\sigma$ is the surround space constant and $G$ is obtained under the constrain

$$\sum_i \sum_j H(i,j) = 1 \qquad (6)$$

An improved rendition is achieved by using a linear combination of three kernels with three different space constants. The values taken for $\sigma^2$ are 4, 40 and80. The combined scale Gaussian ($H_c$) applied here takes the form.

$$H_c(i,j) = \sum_{w=1}^{3} J_w\ G_w\ \exp\left(-\frac{i^2+j^2}{\sigma_w^2}\right) \qquad (7)$$

where

$$J_w = \frac{1}{3}; w = 1,2,3$$

Local average image representing the surround is obtained by 2-D convolution of equation (7) and $P'$ the elements of which are $p'_{N,a,b}$ (in equation (4)) as given by following equation.

$$P_f(i,j) = P' * H_c =$$

$$\sum_{i'=0}^{M-1}\sum_{j'=0}^{N-1} P'(i',j')\, H_c(i-i', j-j') \qquad (8)$$

where $M$ and $N$ are the sizes of the Gaussian kernel $H_c$. Now the contrast enhanced coefficients matrix $P_{new}$ is calculated by equation (9)

$$P_{new} = \begin{cases} 255\bar{P}^R 2^N & for\ R \leq 1 \\ 255\bar{P}^{\frac{1}{R}} 2^N & for\ R > 1 \end{cases} \qquad (9)$$

where the elements of $\bar{P}$ are $\bar{p}_{N,a,b}$ and $R$ is the centre surround ratio given by equation (10).

$$R = \left(\frac{P'}{P_f}\right)^\alpha \qquad (10)$$

where $\alpha$ is the enhancement strength constant. $R$ is matrix which determines whether the centre coefficients are higher than average surrounding intensity or not. If any value of $R$ is less than 1, it is used as a power transform to the corresponding modified coefficient in $\bar{P}$, otherwise the inverse power as indicated by equation (9). Hence we can eliminate halo artifacts or saturation caused by over enhancement.

(iii) Detail coefficient modification: The approximation coefficient modification results in loss of details and edge deterioration. Thus the image quality is restored by appropriate scaling of detail coefficients as shown in equation (). So the coefficients are enhanced using equation (11).

$$Q_{new}^h = \frac{P_{new}}{P} Q^h;\ Q_{new}^v = \frac{P_{new}}{P} Q^v\ ;\ Q_{new}^d = \frac{P_{new}}{P} Q^d \qquad (11)$$

where, $Q_{new}^h, Q_{new}^v$ and $Q_{new}^d$ are modified horizontal, vertical and diagonal coefficients, while $Q^h, Q^v$ and $Q^d$ are the original horizontal, vertical and diagonal coefficients. Now the inverse wavelet transform is performed on the modified approximation and detail coefficients to obtain the enhanced intensity image $I_{enh}$.

### *C. Color restoration*

In order to restore the color of enhanced image, a non-linear approach is employed. The RGB values of enhanced color image are obtained from the RGB values of original color image and the enhanced intensity image as shown in equation (12).

$$I_{CR,m}(i,j) = \mu_m I_{enh}(i,j) \qquad (12)$$

where $\mu_i = \left(\frac{I_m(i,j)}{\max(I_m(i,j))}\right)^\rho$, $m\,\epsilon\,[R,G,B]$ and $\rho$ is the nonlinear gain factor, which adjusts the color saturation to have a better color rendition.

The resultant image $I_{CR}$ thus obtained after color restoration is shown in Figure 2(c).

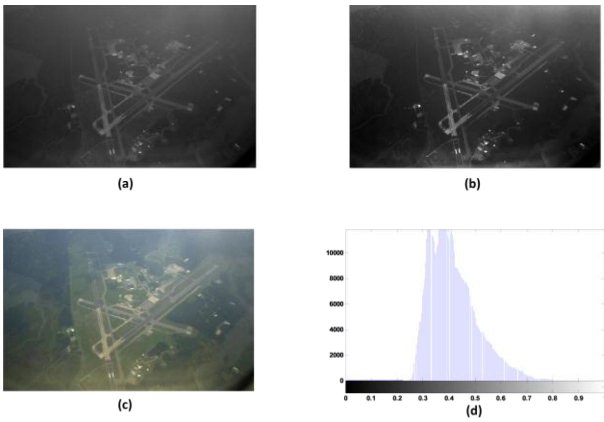


Figure 2: WDRC, LCE and Color restoration. (a) Intensity image I of the input image in Figure 1 (a) (b) Enhanced intensity image I_enh (c) Color restored image I_CR, (d) Histogram of color restored image.

The above results are obtained with values for $r$ and $\alpha$ as 1.2 and 0.2 respectively. The intensity histogram of $I_{CR}$ reveals that the color restored image has a poor contrast as the pixel intensity values are concentrated at the middle portion of the dynamic range. Moreover, close inspection of the Figure 2 (c) indicates a noisy effect resulting from color restoration.

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In this context, it is highly recommended to adopt a post processing step to solve the above mentioned issues.

*D. Post Processing*

From the analysis of intensity histogram in Figure 2(d) and the visual inspection of color restored image in Figure 2(c), some post processing steps are proposed here.

They are Histogram equalization, Laplacian sharpening, Gaussian filtering and Median filtering. Post processing methods restore the edges and sharpen the image, since the image is smoothened during Local contrast enhancegement. But all the methods are not simultaneously applicable. In the algorithm, Laplacian sharpening, Gaussian filtering, median filtering is used for all images, but histogram equalization is an optional one. Median filtering removes noise and histogram equalizations improves the contrast of the image.

(i) Histogram Equalization: As can be seen from Figure 2(d) that the contrast of $I_{CR}$ has to be considerably increased. This can be achieved easily through a straightforward approach called histogram equalization. It is basically a transformation which uniformly distributes the pixel intensity values in the range [0, 1].

(ii) Removal of noise effect: Inspection of Figure 2(c) reveals the presence of some common noises like Gaussian and salt and pepper .The post processing step is also aimed at removing these noisy artifacts added during the color restoration step. The filters employed for this purpose are Gaussian and Median [13] in a sequential manner. The application of median filter after Gaussian filter helps in removing the unwanted impulses in the form of salt and pepper if any present in the image. The Gaussian kernel used for filtering operation is given in equation (13).

$$U(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{\sigma^2}} \qquad (13)$$

In this work, the value of standard deviation $\sigma$ used is 0.5 and the kernel size used for both Gaussian and median filtering is 3x3. Median filtering can preserve discontinuities while it smoothes a few pixels whose values differ significantly from their surroundings without affecting the other.

(iii) Laplacian Sharpening: The application of LCE in step (B) and noisy removal in step (D) using Gaussian kernels causes some blurring of significant edges and discontinuities present in the images. This may affect the quality of the final result. This problem can be solved by sharpening the image at the end of the post processing. In this paper, image sharpening is achieved through a well known procedure called Laplacian sharpening [13]. Laplacian is a second derivative operator which highlights gray level discontinuities while it de-emphasizes regions with slowly varying intensity levels. The Laplacian of the image obtained after noisy removal $F(i,j)$ is given by equation (14).

$$\nabla^2 F(i,j) = \frac{\partial^2 F(i,j)}{\partial i^2} + \frac{\partial^2 F(i,j)}{\partial j^2} \qquad (14)$$

The laplacian mask used in our work is given in equation (15).

$$M_L = \begin{Bmatrix} 0.3103 & 0.3793 & 0.3103 \\ 0.3793 & -2.7586 & 0.3793 \\ 0.3103 & 0.3793 & 0.3103 \end{Bmatrix} \qquad (15)$$

The Laplacian sharpening is implemented according to equation (16) where $Y(i,j)$ is the final output image.

$$Y(i,j) = F(i,j) - \nabla^2 F(i,j) \qquad (16)$$

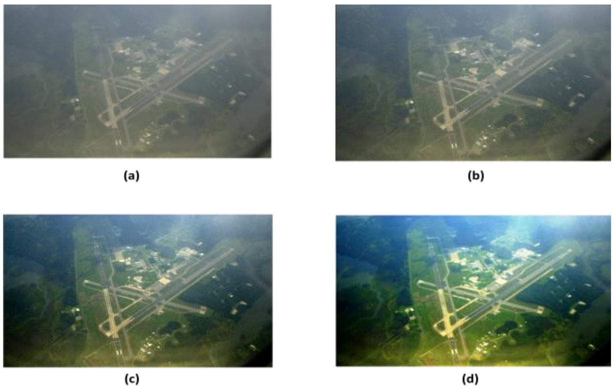

Figure 3: Post processing steps (a) Input image (b) Color restored image I_CR (c) Histogram equalized image, (d) Final output image.

Figure 3 shows the results of post processing steps. Figure 3(a) and 3(b) are the input and color restored images respectively. Figure 3(c) shows the histogram equalized can be seen image in which the contrast has been significantly improved, whereas 3(d) represents the final output image in which the  the noisy effects are considerably reduced along with sharpening the edges.

## III. RESULTS & DISCUSSION

The hybrid processing approach has been applied to several MAV aerial images which suffer from various undesirable atmospheric effects like non-uniform lighting conditions, turbidity, haze, fog, clouds etc. The results thus obtained are compared with existing aerial image enhancement methods like MSRCR, LTSN, AINDANE and Automatic WDRC. This section also presents a discussion on the selection of parameters $r$ (curvature parameter),$\alpha$ (enhancement strength constant) and $\rho$ (nonlinear gain factor).

The optimum values of $r$, $\alpha$ and $\rho$ obtained empirically are 1.15, 0.1 and 2 respectively. This selection has been done through visual inspection of final output images after the application of proposed algorithm to around 100 aerial images suffering from undesirable atmospheric effects with different combinations of $r$, $\alpha$ and $\rho$. The optimum value of $\rho$ is determined only after $r$ and $\alpha$ have been optimized. Here we have considered 200 different combinations of $r$ and $\alpha$ to optimize their values. Figure 3 shows the final output for only four different combinations of $r$, $\alpha$ and $\rho$. For $r = 1.15$ and $\alpha = 0.1$, which are their optimum values, 50 different cases of $\rho$ have been taken into account while finalizing its optimum value which is 2. It is very obvious from Figure 3 that combination corresponding to (d) is visually superior to all the other combinations in terms of contrast enhancement, luminance distribution, color rendition and detail preservation.


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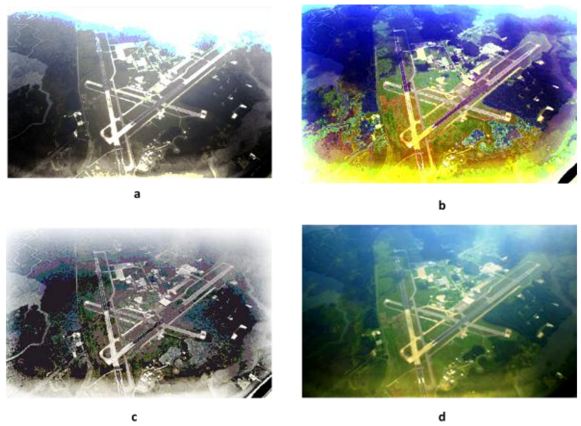

Figure 4: Optimizing r, α and ρ (a) r=2.5, α=0.4 and ρ=0.5 (b) ) r=2, α=0.3 and ρ=3.5 (c) ) r=1.5, α=0.25 and ρ=1 (d) ) r=1.15, α=0.1 and ρ=2

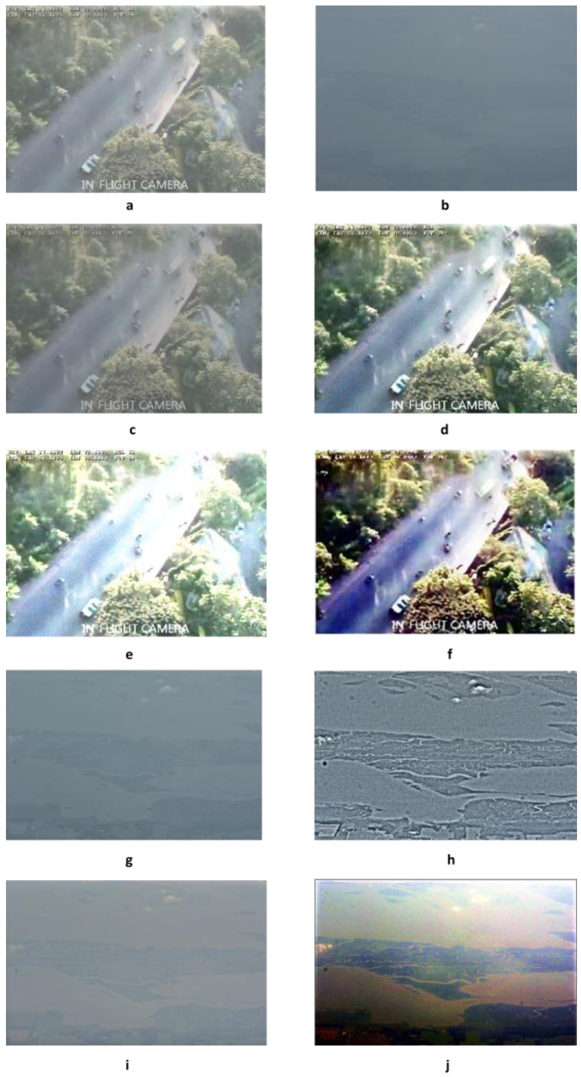

Figure 5: Performance comparison of proposed method with other existing aerial image enhancement methods. (a) Input image 1.(b) Input image 2. (c), (d), (e) & (f) are the final output images of AINDANE, LTSN, MSRCR and proposed methods for input image 1. (g), (h), (i) & (j) are the final output images of AINDANE, LTSN, MSRCR and proposed methods for input image 2.

Figure 5 shows the performance comparison of proposed technique with existing aerial image enhancement methods like AINDANE, LTSN and MSRCR through visual inspection [14]. The comparison has been done using 100 MAV aerial images taken at an altitude of around 70 to 90 meters. Most of the captured images were subjected to undesirable atmospheric effects like fog, snow, haze and some noisy artifacts. The captured images were of size 640x480 in RGB format with a bit depth of 24. Figure 5(a) is an input image with poor contrast and contaminated with atmospheric noise. The results of AINDANE, Figure 5 (c), and MSRCR, 5 (e), do not show a noticeable enhancement. Although LTSN algorithm, Figure 5 (d), performs relatively well, it lacks a proper contrast enhancement and color rendition. The result shown in Figure 5 (f) corresponds to the proposed method which achieves a significant improvement over other methods. Figure 5(g), (h) and (i), the outputs of AINDANE, LTSN and MSRCR, do not reveals anything more than the input image in Figure 5(b). But from the result in Figure 5 (j), it is very obvious that the proposed algorithm outperforms the existing ones in terms of contrast enhancement, luminance distribution, color rendition, edge sharpening and detail preservation. The algorithm is implemented in MATLAB 2013a.

## IV. CONCLUSION

A new algorithm, incorporating both spatial and frequency domain analysis for aerial image enhancement is presented in this paper. The scheme, based on *Wavelet-based Dynamic Range Compression*, has been found to be efficient in enhancing images, particularly aerial images taken by cameras of MAVs, to desirable levels. The enhancement to a satisfactory level could be achieved only through a post processing step which involves histogram equalization, removal of noise artifacts and Laplacian sharpening. The enhanced images are found to preserve all the original details. The algorithm can be easily implemented and can be used very effectively in a number of applications of UAVs and MAVs.

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