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# Automatic Wavelet-based Nonlinear Image Enhancement for Aerial Imagery

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**ABSTRACT**

*A proposed wavelet-based dynamic range compression algorithm is used to improve the visual quality of digital images captured in the high dynamic range scenes with nonuniform lighting conditions. The fast image enhancement algorithm which provides dynamic range compression preserving the local contrast and tonal rendition is a very good candidate in aerial imagery applications such as image interpretation for defense and security tasks. This algorithm can further be applied to video streaming for aviation safety. In this paper the latest version of the proposed algorithm which is able to enhance aerial images so that the enhanced images are better then direct human observation, is presented. The results obtained by applying the algorithm to numerous aerial images show strong robustness and high image quality.*
*Keywords: Aerial imagery, Wavelet based enhancement, Low contrast*

## 1. INTRODUCTION

Aerial images captured from aircrafts, spacecrafts, or satellites usually suffer from lack of clarity, since the atmosphere enclosing Earth has effects upon the images such as turbidity caused by haze, fog, clouds or heavy rain. The visibility of such aerial images may decrease drastically and sometimes the conditions at which the images are taken may only lead to near zero visibility even for the human eyes. Even though human observers may not see much than smoke, there may exist useful information in those images taken under such poor conditions.

Captured images are usually not the same as what we see in a real world scene, and are generally a poor rendition of it. High dynamic range of the real life scenes and the limited dynamic range of imaging devices results in images with locally poor contrast. Human Visual System (HVS) deals with the high dynamic range scenes by compressing the dynamic range and adapting locally to each part of the scene. There are some exceptions such as turbid (e.g. fog, heavy rain or snow) imaging conditions under which acquired images and the direct observation possess a close parity [1]. The extreme narrow dynamic range of such scenes leads to extreme low contrast in the acquired images.

To deal with the problems caused by the limited dynamic range of the imaging devices, many image processing algorithms have been developed [2]-[17]. These algorithms also provide contrast enhancement to some extent.

Recently we have developed a wavelet-based dynamic range compression (WDRC) algorithm to improve the visual quality of digital images of high dynamic range scenes with non-uniform lighting conditions [18]-[19]. The WDRC algorithm is modified in [20] by introducing an histogram adjustment and non-linear color restoration process so that it provides color constancy and deals with “pathological” scenes having very strong spectral characteristics in a single band. The fast image enhancement algorithm which provides dynamic range compression preserving the local contrast and tonal rendition is a very good candidate in aerial imagery applications such as image interpretation for defense and security tasks. This algorithm can further be applied to video streaming for aviation safety. In this paper application of the WDRC algorithm in aerial imagery is presented. The results obtained from large variety of aerial images show strong robustness and high image quality indicating promise for aerial imagery during poor visibility flight conditions.

## 2. ALGORITHM

The proposed enhancement algorithm consists of three stages: the first and the third stage are applied in the spatial domain and the second one in the discrete wavelet domain.

### *A. Histogram Adjustment*

Our motivation in making an histogram adjustment for minimizing the illumination effect is based on some assumptions about image formation and human vision behavior. The sensor signal $S(x, y)$ incident upon an imaging system can be approximated as the product [8],[20]

$$S(x,y) = L(x,y)R(x,y) \quad \text{...................... (1)}$$

where $R(x, y)$ is the reflectance and $L(x, y)$ is the illuminance at each point $(x, y)$.

In lightness algorithms, assuming that the sensors and filters used in artificial visual systems possess the same nonlinear property as human photoreceptors, i.e., logarithmic responses to physical intensities incident on the their photoreceptors [8], Equation 1 can be decomposed into a sum of two components by using the transformation I(x,y) = log(S(x,y)):

$$I(x,y) = \log(L(x,y)) + \log(R(x,y)) \quad \text{......................} \ (2)$$

where $I(x,y)$ is the intensity of the image at pixel location $(x,y)$.

Equation 2 implies that illumination has an effect on the image histogram as a linear shift. This shift, intrinsically, is not same in different spectral bands.

Another assumption of the lightness algorithms is the grayworld assumption stating that the average surface reflectance of each scene in each wavelength band is the same: gray [8]. From an image processing stance, this assumption indicates that images of natural scenes should contain pixels having almost equal average gray levels in each spectral band.

Combining Equation 2 with the gray-world assumption, we perform histogram adjustment as follows:

1. The amount of shift corresponding to illuminance is determined from the beginning of the lower tail of the histogram such that a predefined amount of image pixels is clipped.
2. The shift is subtracted from each pixel value.
3. This process is repeated separately for each color channel.

***B. Wavelet Based Dynamic Range Compression and Contrast Enhancement***

***1. Dynamic Range Compression***

Dynamic range compression and the local contrast enhancement in WDRC are performed on the luminance channel. For input color images, the intensity image $I(x,y)$ can be obtained with the following equation:

$$I(x,y) = \max[I_i(x,y)],\ i\epsilon \{R,G,B\} \quad \text{....................} \ (3)$$

The enhancement algorithm is applied on this intensity image. The luminance values are decomposed using orthonormal wavelet transform as shown in (4):

$$I(x,y) = \sum_{k,l\in z} a_{J,k,l}\Phi_{J,k,l}(x,y) + \sum_{j\geq J}\sum_{k,l\in z} d^h{}_{j,k,l}\Psi^h{}_{j,k,l}(x,y) + \sum_{j\geq J}\sum_{k,l\in z} d^v{}_{j,k,l}\Psi^v{}_{j,k,l}(x,y) + \sum_{j\geq J}\sum_{k,l\in z} d^d{}_{j,k,l}\Psi^d{}_{j,k,l}(x,y) \quad \text{................} \ (4)$$

Where $a_{j,k,l}$ are the approximation coefficients at scale $J$ with corresponding scaling functions $\Phi_{J,k,l}(x,y)$ and $d_{j,k,l}$ are the detail coefficients at each scale with corresponding wavelet functions $\Psi_{j,k,l}(x,y)$. A raised hyperbolic sine function given by Equation 5 maps the normalized range [0,1] of $a_{J,k,l}$ to the same range, and is used for compressing the dynamic range represented by the coefficients. The compressed coefficients at level $J$ can be obtained by

$$\bar{a}_{J,k,l} = \left[\frac{\sinh(4.6248a'_{J,k,l} - 2.3124) + 5}{10}\right]^r \quad \text{.....................} \ (5)$$

where $a'_{J,k,l}$ are normalized coefficients given by

$$a'_{J,k,l} = \frac{1}{255}\frac{a_{J,k,l}}{2^J} \quad \text{............} \ (6)$$

***2. Local Contrast Enhancement***

The local contrast enhancement which employs a center/surround approach is carried out as follows:

The surrounding intensity information related to each coefficient is obtained by filtering the normalized approximation coefficients with a Gaussian kernel.

$$G(x,y) = \kappa \exp\left(-\frac{x^2+y^2}{\sigma^2}\right) \quad \text{.......................} \ (7)$$

where σ is the surround space constant, and k is determined under the constraint that

$$\sum_x\sum_y G(x,y) = 1 \quad \text{......................} \ (8)$$

Local average image representing the surround is obtained by 2D convolution of (7) with image $A'$, the elements of which are the normalized approximation coefficients $a'_{J,k,l}$ and given by (6) :

$$A_f(x,y) = A'(x,y) * G(x,y) = \sum_{x'=0}^{M-1}\sum_{y'=0}^{N-1} A'(x',y')G(x-x',y-y') \quad \text{............} \ (9)$$

The contrast enhanced coefficients matrix $A_{new}$ which will replace the original approximation coefficients $a_{J,k,l}$ is given by,

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$$A_{new} = \begin{cases} 255\bar{A}^{R}2^{J} & for\ R \le 1 \\ 255\bar{A}^{\left(\frac{1}{R}\right)}2^{J} & for\ R > 1 \end{cases} \quad \text{............ (10)}$$

where, $R$ is the centre/surround ratio given by $R = (A^{'}/A_{f})^{d}$, $d$ is the enhancement strength constant with a default value of 1; $\bar{A}$ is the matrix whose elements are the output of the hyperbolic sine function in (5).

A linear combination of three kernels with three different scales, combined-scale-Gaussian ($Gc$ ), is used for improved rendition is given by

$$G_{c}(x,y) = \sum_{k=1}^{3} W_{k}\kappa_{k}\exp\left(-\frac{x^{2}+y^{2}}{\sigma_{k}^{2}}\right), \quad W_{k} = \frac{1}{3}, k = 1,\ldots,3 \quad \text{............. (11)}$$

***3. Detail Coefficient Modification***

The detail coefficients are modified using the ratio between the enhanced and original approximation coefficients. This ratio is applied as an adaptive gain mask such as:

$$D_{new}^{h} = \frac{A_{new}}{A}D^{h}; \quad D_{new}^{v} = \frac{A_{new}}{A}D^{v}; \quad D_{new}^{d} = \frac{A_{new}}{A}D^{d} \quad \text{........ (12)}$$

where $A$ and $Anew$ are the original and the enhanced approximation coefficient matrices at level 1; $D^{h}$ , $D^{v}$ , $D^{d}$ are the detail coefficient matrices for horizontal, vertical and diagonal details at the same level, and $D^{h}_{new}$ , $D^{v}_{new}$ , $D^{d}_{new}$ are the corresponding modified matrices, respectively. If the wavelet decomposition is carried out for more than one level, this procedure is repeated for each level.

***C. Color Restoration***

A linear color restoration process is used to obtain the final color image in our previous work [23,24]. For WDRC with color restoration[25], a non-linear approach is employed. The RGB values of the enhanced color image $I_{enh,\,i}\,(x, y)$ , along with the CR factor are given as:

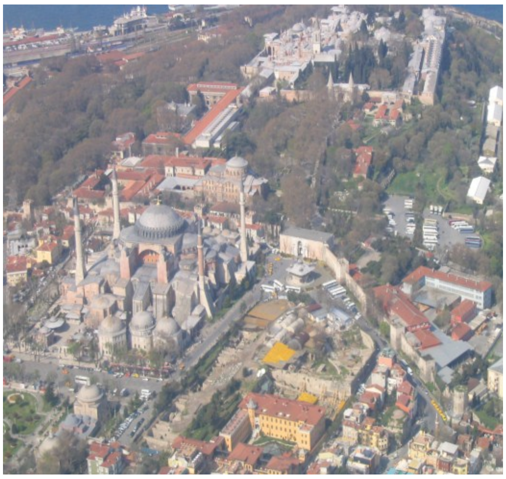
$$I_{enh,i} = \alpha_{i}I_{enh}, \alpha_{i} = \left(I_{i}(x,y)/\max\left(I_{i}(x,y)\right)\right)^{\beta} \quad \text{............ (13)}$$

where $I_{i}\,(x, y)$is the RGB values of the input color image at the corresponding pixel location and $I_{enh}\,(x, y)$ is the resulting enhanced intensity image derived from the inverse wavelet transform of the modified coefficients. Here β is the non-linear gain factor corresponding. This factor has a canonical value and increases the color saturation resulting in more appealing color rendition.

Since the coefficients are normalized during the enhancement process, the enhanced intensity image obtained by (15) the inverse transform of enhanced coefficients, along with the enhanced color image given by span almost only the lower half of the full range of the histogram. For the final display domain output $I_{enh,\,i}$'s in (15) are stretched to represent the full dynamic range. Histogram clipping from the upper tail of histograms in each channel give the best results in converting the output to display domain.

## 3. RESULTS

The proposed algorithm has been applied to numerous aerial images with different degree of turbidity. The results show improved clarity i.e. the increased visibility distance for haze, fog, clouds and heavy rain. The algorithm works well for images captured in diverse flight conditions.



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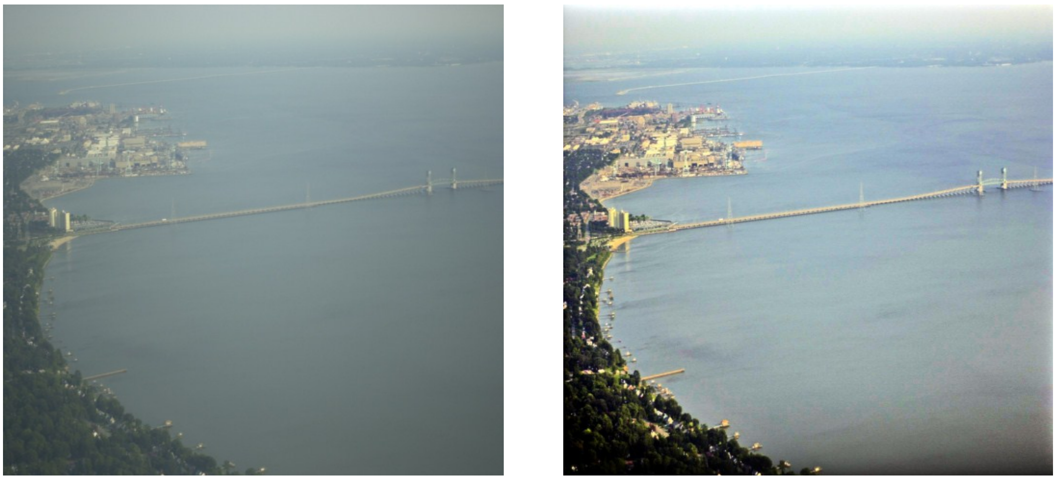

**(a) Original Image** **(b) Enahanced Image**

**Figure: The enhancement results for different types of turbidity**

Some examples for such conditions are shown in Figure. In Figure left column shows the original images and right column shows the enhanced WDRC results. The first example shows a scene with mild haze, proposed algorithm completely removes the haze resulting in sharper image with saturated colors. The scene in the second row suffer from moderate fog with some smoke. Good clarity achieved and the colors of the scene content are restored in the enhanced image. In the enhanced image visibility of features is improved significantly. The last row is an example of a scene with near zero visibility. The enhaced images achieves a high level of improvement to feature visibility removing the severe turbidity.

Another advantage of the proposed algorithm is its speed. Since the convolutions that take most of the processing time are only applied to approximation coefficients, the processing time is reduced to almost half the processing time required for IRME which is known to be designed for real time video processing on PC platforms.

## CONCLUSIONS

In this paper application of the WDRC algorithm in aerial imagery is presented. The results obtained from large variety of aerial images show strong robustness, high image quality, and improved visibility indicating promise for aerial imagery during poor visibility flight conditions. This algorithm can further be applied to real time video streaming and the enhanced video can be projected to the pilot's heads-up display for aviation safety.

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