An Alpha Rooting Based Hybrid Technique for Image Enhancement

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***Abstract*— The conventional transform domain image enhancement technique of alpha rooting has long been used for enhancing high contrast edge information and sharp features in images. However the alpha rooting technique is constrained by problems like overall graying, tonal changes and noisy artifacts. This paper explores a new method by which alpha rooting can be used for enhancing even low contrast images. In this paper we advocate complementing the transform domain technique with appropriate spatial domain techniques to eliminate the limitations of the conventional transform domain technique, thus improving the image enhancement process. We suggest an alpha rooting based Hybrid Technique by combining the gray level transformation algorithms, such as logarithmic transform and power law transform, with alpha rooting algorithm for contrast enhancement. The new technique which ensures control over the contrast of the image to the desired degree is inherently simple in theory and implementation and is well suited for enhancement of a variety of images.**

***Index Terms*— Image enhancement, alpha rooting, power law transformation, logarithmic transformation, high frequency content, contrast enhancement, edge enhancement.**

I. Introduction

CURRENT research in image enhancement covers such wide topics as algorithms based on the human visual system, histograms with hue preservation, JPEG-based enhancement for the visually impaired and, histogram equalization and modification techniques. Image enhancement techniques are broadly classified as spatial domain techniques and frequency domain techniques. Spatial domain techniques like the logarithmic transforms, power law transforms, histogram equalization, are based on the direct manipulation of the pixels in the image plane, while the transform domain techniques are based on the manipulation of the orthogonal transform of the image rather than the image itself [1 - 21].

Spatial techniques are particularly useful for directly altering the gray level values of individual pixels and hence the overall contrast of the entire image. But they usually enhance the whole image in a uniform manner which in many cases produces undesirable results. It is not possible to selectively enhance edges or other required information effectively. Techniques like histogram equalization are effective in many images. But they produce unbalanced and noisy results in many images with an irregular distribution of gray levels and those that have low contrast, as is shown in Figure 1 (b) of the U2 image.

On many images, histogram equalization provides satisfactory to good results, but there are a number of images where it fails to properly enhance an image [6]. Problems with histogram equalization can be artifacts and overall brightness change in the resulting image. Many alterations of histogram equalization have been proposed to counter the affects of this range expansion [6]. The most basic is local histogram equalization using sub-blocks. These techniques have their own variations such as non-overlapping and overlapping with temporal filtering to reduce artifacts [8]. Non-overlapping local histogram equalization normally results in ugly blocking artifacts [8].

Transform domain techniques are suited for processing the image according to the frequency content. The usual orthogonal transforms are discrete cosine transform, discrete Fourier transform, Hartley Transform *etc.* [11]. Enhancement techniques such as alpha rooting [12 - 18], operate on the transform domain. The transform domain enables operation on the frequency content of the image, and therefore high frequency content such as edges and other subtle information can easily be enhanced. However, these techniques bring about tonal changes in the images and can also generate unwanted artifacts in many cases, as it is not possible to enhance all parts of the image in a balanced manner. The overall tone of the resultant image is usually darker notwithstanding the enhanced sharpness, thus resulting in a deterioration of the image quality. Moreover, the complexity in implementation of the transform domain techniques compared to the spatial domain technique becomes an additional limitation.

We have resorted to basic frequency domain transforms and techniques in this paper. However it should be noted that current advancements in the field centers on more advanced measures than the normal frequency domain transforms. Transforms like the Fourier transform have been increasingly replaced with the wavelet transform [27]. Wavelet transforms are localized in both time and frequency whereas Fourier transform is localized only in frequency. Partial differential equations (PDEs) are another technique that has been increasingly employed in the field. It can be used to

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supplement the non linear transformation techniques. This is especially effective in applications like enhancement by edge sharpening and noise reduction [25]. Edge enhancement on color images based on structure tensors and geometric measures have been a new development [26]. In the spatial domain also conventional techniques have been replaced by innovative technology like histogram equalization based on mesh deformation [28-32]. Such a scenario where advanced research is still going on calls for far better possibilities in using a combination of spatial and frequency domain techniques.

Against this background, we looked at a combined frequency domain and spatial domain enhancement technique, wherein the frequency domain technique complements the spatial domain technique in order to optimize the advantages and minimize the limitations of both the techniques. This paper discusses an algorithm in which the alpha rooting transform domain technique is coupled with the spatial domain technique. Alpha rooting is usually used to accentuate the high frequency content of the image. It is well known that power law transforms and log transforms can be used to map a narrow range of input gray levels to a wider output range thereby improving contrast. Hence by subjecting the result of alpha rooting to power law and log transforms, we advocate that the overall contrast can effectively be enhanced, at the same time retaining the subtle information and perceivable detail brought out by alpha rooting.

Thus the new technique will be able to enhance the subtle edge information along with the contrast which together produces excellent visual quality. We demonstrate in the following sections that the new technique creates a more balanced and better enhancement when applied on a variety of images, including low contrast images and images with unbalanced distribution of grey levels. The technique is also simple in theory and implementation, and is more efficient than many other conventional techniques.

A measure of enhancement [12], [13], [19], [20] based on contrast entropy was used to measure the results. This measure is more in conjunction with the visual quality and perceivable detail of the image. This measure uses elements similar in nature to human visual perception. The Tenengrad measure which is a recognized calibration in image enhancement is also used to measure the results.

II. Background

A. *Transform Domain Techniques*

The transform domain enables us to view the frequency content of the image. This is usually done by taking the discrete cosine transform, the discrete Fourier transform or any other orthogonal transform [9–11] of the image. The principle behind the transform-based methods of image enhancement consists of computing a 2-D discrete unitary transform of the image, for instance the 2-D DFT, manipulating the transform coefficients by an operator M, and then performing the inverse transform. The orthogonal transform of the image has two components: the magnitude and the phase. The magnitude consists of the frequency content of the image. The phase is used to restore the image back to the spatial domain. It holds the relative positioning information (angle) of the magnitude content. The frequency domain of images is clearly depicted in the mathematical form as

$$X(p,s) = |X(p,s)|\, e^{j\theta(p,s)} \qquad (1)$$

where $X(p,s)$ is the orthogonal transform of the image, $|X(p,s)|$ is the magnitude of the transform and $\theta(p,s)$ is the phase angle of the transform.

Transform domain techniques operate on the magnitude component of the orthogonal transform. In this step various alterations to the frequency content as desired are made. After processing, the magnitude is combined with the phase and the inverse orthogonal transform is applied to obtain the resultant image [9] [10].

Alpha Rooting Technique: Alpha rooting [12 - 19] is a simple but effective technique of image enhancement in the frequency domain. The technique is applied on the orthogonal transforms of images such as Fourier, discrete cosine or Hartley transforms. It is used to augment the high frequency content in the image. The visual result presents a higher emphasis on detail such as edges and fine distinguishing features.

The method is based upon the fact that after applying an orthogonal transform, high frequency coefficients of an image, will have smaller magnitudes than low frequency coefficients. By raising the magnitude of an image to some value, α, where $0 < \alpha < 1$, the higher valued lower frequency components of an image can be reduced more in proportion to the lower valued high frequency components. This proportional reduction of magnitudes leads to an emphasizing of high frequency content on an image. The mathematical form of the operation is

$$\hat{X}(p,s) = |X(p,s)|^{\alpha}\, e^{j\theta(p,s)} \qquad (2)$$

where $|X(p,s)|$ is the magnitude of the image transform, $\theta(p,s)$ is the phase of the transform and α is the value by which the magnitude is raised ($0 < \alpha < 1$), $\hat{X}(p,s)$ is the result of alpha rooting. Applying inverse orthogonal transform on $\hat{X}(p,s)$ returns the image enhanced by alpha rooting.

The resultant image after alpha rooting has pronounced vividness in areas like edges; it has sharper features and hence more decipherable information than the original image.

Notwithstanding the enhancement of edges and sharpness, the technique does not produce a much desired visual result on many images. This is because the procedure brings about a tonal change [21], in the image which manifests in the form of an overall greying of the image. The effect is observable in most of the images on which alpha rooting is applied and becomes more pronounced in case of darker original images. Thus many a time, the output image, although sharp, is unacceptably dark; it is poor in contrast and brightness expected of a good enhancement. This is evident in Fig. 2 (c) which shows the result of applying alpha rooting to the copter image. In such cases, the alpha rooting technique renders the output image almost futile for further processing or applications. Another disadvantage of the technique is appearance of ugly artefacts in the output image and the unwanted enhancement of noise in the image. The proposed modified method strives to alleviate the above disadvantages especially those regarding the greying of the image.

B. *Spatial Domain Techniques*

Log Transformation Technique : Log transformations [9] [10] [19] are one of the elementary image enhancement techniques of the spatial domain that can be effectively used for contrast enhancements of dark images. The log transform is essentially a grey level transform which means that the grey levels of image pixels are altered. This transformation maps a narrow range of low grey level values in the input image to a wider range of output levels. The opposite is true for higher input grey levels. Thus the dark input values are spread out into the higher gray level values which improve the overall contrast and brightness of the image. The general form of the log transformation can be mathematically represented as

$$s = c \log (1 + r) \qquad (3)$$

where, s is the output grey level, r is the input grey level and c is a constant. It is assumed that $r \geq 0$.

Power Law Transformation Technique: Power law transformation [9, 10] is another commonly used gray level transformation in the spatial domain. It is conceptually similar to alpha rooting in the frequency domain as this is done by raising the input grey level by some power, γ. It is similar in operation to the log transforms in that power law transforms with fractional values of γ map a narrow range of dark input values into a wider range of output values thereby increasing the contrast. However the difference is that unlike the log function, there is an assortment of possible transformation curves obtained by varying the power γ. As the power γ, varies the nature of mapping of the input grey levels to output grey levels changes. The transformation can be mathematically represented as

$$s = b\, r^{\gamma} \qquad (4)$$

where s is the output grey level, r is the input grey level, b is a scaling constant and γ is the power to which the input grey level is raised. One significant advantage of the transformation is that it is possible to control the transformation function by varying the parameter γ. We can make the image tone darker or brighter by changing the γ values. A point worth noting is that values of $\gamma < 1$ expand a narrow range of dark grey levels to a wider range. This makes the overall tone brighter. The reverse holds for $\gamma > 1$.

III. An Alpha Rooting Based Hybrid Contrast Enhancement Procedure

Conventional alpha rooting results in an enhancement of subtle edge information in images. It increases the sharpness and makes the image crisper. But this enhancement in sharpness is most often subdued by the overall darkening of the image which is artifact of alpha rooting [21]. This artifact therefore necessitates the development of a new method by which the tonal change can be eliminated or rather reversed thus achieving good contrast and brightness also. Here we discuss a procedure based on alpha rooting technique for achieving balanced enhancement of images. In this section, we discuss the procedure of combining spatial enhancement techniques such as log transforms and power law transforms with alpha rooting in order to enhance the quality of the image.

As mentioned earlier, the algorithm was developed on lines of an exploration into the possibilities of combining spatial and frequency domain techniques of image enhancement. In this regard we chose those techniques from each domain having a basic nature, simplicity and ease of experimentation and at the same time being efficient also. Log transform and power law transform in the spatial domain account for techniques that are not complex but at the same time provide powerful enhancement. They were chosen especially for their power to map grey values across spectrum with the aid of parameters. This provides with flexibility to mix and match these parameters and mappings (with the result of alpha rooting procedure) to get optimum enhancement. Alpha Rooting itself was chosen because it is one of the most basic techniques in the frequency domain which contributes to good sharpening and enhancement of images. This technique also holds the flexibility of a parameter aided operation which is highly appreciated for experimenting with different levels of enhancement. Also by employing such basic and simple techniques we can sidestep major performance overheads which would entail in case of a combination of more complex techniques from the domain. Needless to say, this would enhance both experimental and operational efficiency. These techniques are not exhaustive in such an approach and further research could be carried out by substituting other techniques from the domain.

The first step in the proposed method would be to take the orthogonal transform of the input image. The usual transforms are Fourier transform, discrete cosine transform *etc*. which transform the image into the frequency domain. In this paper we have chosen the Discrete Cosine Transform (DCT) for the demonstrations. Then the magnitude and the phase of the frequency transform coefficients are separated. The next step would be to apply alpha rooting to the magnitude of the coefficients. After this, the phase is restored and the inverse orthogonal transform is applied to get the output image of alpha rooting.

The result of alpha rooting, as earlier mentioned, is many a time poor in contrast and brightness and suffers from the graying effect. To counter this problem, we subject the result to spatial gray level contrast enhancement transforms. Hence, as the next step the log transform is applied to the output image of alpha rooting. This process scales the narrow range of dark values to a wider range. This result is then subjected to the power law transformation which results in additional enhancement. This step also allows us to control the level and extent of enhancement by varying the power parameter. The addition of the log transform and power law transform enhances the quality of the image with good contrast and brightness. The process is depicted in the algorithm stated in the subsequent section.

A. *Algorithm*

The algorithm for the procedure is as follows:

Input : Original Image

Step 1: Transform the Image using DCT.

Step 2: Separate magnitude and phase of the transform coefficients

$$X(p,s)=|X(p,s)|e^{j\theta(p,s)}$$

where $X(p,s)$ is the orthogonal transform of the image, $|X(p,s)|$ is the magnitude of the transform and $\theta(p,s)$ is the phase angle of the transform.

Step 3: Apply alpha rooting to magnitude coefficients

$$|X(p,s)|^{\alpha}$$

where $|X(p,s)|$ is the magnitude of the image transform, $\theta(p,s)$ is the phase of the transform and α (alpha) is the value by which the magnitude is raised (0<α<1),

Step 4: Combine the phase angle to the alpha rooted magnitude

$$\hat{X}(p,s)=|X(p,s)|^{\alpha}e^{j\theta(p,s)}$$

where $\hat{X}(p,s)$ is the result of alpha rooting.

Step 5: Apply Inverse orthogonal transform to return from frequency domain to spatial domain

Step 6: Take the result of step 5 and apply log transform to each pixel location (grey level)

$$s = c\log(1 + r)$$

where r is the grey level of the input pixel, s is the grey level of the corresponding output pixel. c is a scaling constant.

For work related to this paper we have calculated c as follows:

$$c = 1.5 * max$$

where *max* is the maximum gray level value in the alpha rooted image (result of alpha rooting obtained in step 5).

Step 7: To the result of step 6 apply the power law transformation

$$s = b\,r^{\gamma}$$

where r is the input grey level, s is the output grey level, b is a scaling factor and γ is the power to which the input grey level is raised. The scaling factor b and power γ are used as variable parameters and may be varied accordingly to find the optimum enhancement point.

Output: The result of step 7 produces the enhanced output image.

IV. Performance Evaluation and Parameter Selection

For many images, the evaluation of enhancement is the human visual perception. But as it is highly subjective there should a well defined objective measure to quantify the enhancement. This assumes importance in cases where the enhancement is trivial or difficult to be measured visually. Such situations may occur when enhancement is used as a preprocessing step for other image processing applications. A quantitative measure is also needed in case of parameter based algorithms to identify the optimum enhancement point. When there is a need to compare the results of two enhancement techniques, a quantitative measure is highly imperative.

Many measures of enhancement exist, but few exhibit consistencies over all types of images [7]. Many measures of enhancement do not show expected measurements in images exhibiting obvious visual contrast improvement [4].

We have chosen the measure of enhancement by entropy (EME) [12], [13], [20] for evaluating our enhancement results. This measure is based on entropy of contrast established on the foundation of the Michelson contrast measure [19] and uses elements of human visual perception. The central idea is to divide the image into blocks and use the ratio between the maximum and minimum intensity value in the blocks. This essentially relates to the contrast of grey level values present in the blocks. Keeping in line with the logarithmic nature of human visual perception, a logarithmic compression of the ratio is also done. The values collected from individual blocks are averaged over the entire image. Since this process is essentially a way of measuring the entropy, or information, in the contrast of the image [19] a higher value of EME denotes a higher contrast and information clarity in the image.

The image to be evaluated is first divided into $k_1 \times k_2$ blocks where each block has a particular size. For this paper, we have used a block size of 4 x 4. Using a smaller block size produces a more accurate result, but increases processing time. Then the maximum and minimum luminance values in each block are found out. The EME is calculated as per the following equation:

$$\text{EME} = \frac{1}{k_1k_2}\sum_{l=1}^{k_2}\sum_{k=1}^{k_1}\frac{I_{\max}(k,l)}{I_{\min}(k,l)}\log\frac{I_{\max}(k,l)}{I_{\min}(k,l)} \qquad (4)$$

where $k_1 \times k_2$ is the total number of blocks in the image, $I_{\max}(k,l)$ is the maximum grey level value in the block (k, l) and $I_{\min}(k,l)$ is the minimum grey level value in the block. A very small constant p is usually added to the denominator to avoid division by zero.

This measure of enhancement employs a more structured and rational approach than other measures to quantify contrast enhancement. It is a more reliable and accurate measure owing to the use of contrast entropy and other elements of visual perception. The measure shows considerable consistency and correctness that is more in conjunction with the visual quality and perceptibility of the image.

Enhancement of edges and sharp, fine information is also achieved by our procedure. So there should be a measure to determine the extent of edge enhancement. For this purpose, the well known and established Tenengrad measure is employed. The Tenengrad measure is based on gradient magnitude maximization. The Tenengrad value of an image I is calculated from the gradient $\nabla I(x,y)$ at each pixel location (x,y), where the partial derivatives are obtained by a high pass filter like the Sobel operator, with the convolution kernels i_x and i_y . The gradient magnitude is given as

$$S(x,y)=\sqrt{(i_x \times I(x,y))^2+(i_y \times I(x,y))^2} \qquad (5)$$

The Tenengrad criteria is then calculated as

$$\text{TEN} = \sum_x \sum_y S(x,y)^2 \qquad (6)$$

For $S(x,y)>T$, where T is a threshold. The image quality in terms of sharpness and edge information is usually considered higher if the Tenengrad value is larger.

A. *Selection of Optimal Parameters*

The proposed algorithm may be implemented as a parameter based procedure. This ensures flexibility in controlling the extent of enhancement by varying the parameters and also enables the user to find the optimum enhancement point. In this approach, we take a specific image and operate the algorithm on it iteratively, each time with a different value for the parameters. The best results can be found out by analyzing the output images using the performance evaluation measures and also by visual appreciation. The parameters used to obtain this best enhancement result are selected as the optimum enhancement point for the particular image.

We have selected the following quantities as variable parameters for work related to this paper.

(a) The alpha rooting coefficient α (alpha)

(b) The power coefficient γ in the power law transformation

(c) The scaling factor *b* in the power law transformation

For any particular image several runs of the algorithm are to be carried out varying the values of the parameters each time. Each time, the EME of the enhanced image is calculated. The result having the highest EME value is usually the optimum result in terms of contrast and entropy. In many cases, a visual analysis of perception and clarity is imperative to confirm the best result. Generally it can be formulated that if the enhanced image has a reasonable increase in EME with respect to the input image, then there is a considerable contrast enhancement. Analysis of the enhanced image with respect to the Tenengrad criteria is also carried out to measure the improvement in edge information and sharpness.

V. Results and Discussion

Alpha Rooting Based Hybrid Procedure was applied on many images spanning an assortment of contrast levels and qualities. However, the stress has been to apply the algorithm on low contrast gray scale images. Many of these images are dull in tone and there is very less perceivable detail in the original images. Conventional techniques like histogram equalization failed to enhance the image properly. In many such images, conventional techniques either over-enhanced the image, rendering it rather unrecognizable or under-enhanced them resulting in a poor quality image. The conventional techniques also under-performed in extracting hidden details and the visual results were of poor quality. Our procedure produced a more balanced and natural result in such images. The enhanced result was also visually appealing and realistic. In implementing this procedure, significance has been placed to produce practical results for real world image enhancement. The main goal has been to produce a useful enhancement, one in which the results are solid and perceivable, and therefore our focus was on applying the algorithm on images where conventional techniques such as histogram equalization fail.

The experimental results were compared against three main conventional techniques – histogram equalization [9], [10], adaptive histogram equalization [10], [20] and alpha rooting. The demonstrated results show the efficacy of the new procedure over the conventional techniques. The resultant images were compared in terms of EME, Tenengrad and also the visual quality and perceptibility.

The first image chosen for demonstrating results was the U2 image (top view of the plane). This image is characteristically dark and dull. It has grey levels concentrated over the dark end of the spectrum. Much of the image detail is obscured by this dark tone. The quality of the images after applying the Histogram equalization and alpha rooting techniques were far from satisfactory as can be seen in Figure 1.

The original image has an EME of 3.7920. Histogram equalization produced a skewed enhancement which overemphasized the background and changed the overall tone of the image. The contour lines and noise in the background were over-enhanced. The inability to discern the localized intensity changes due to the washed out effect on the plane in the image has degraded the visual quality. The EME of the histogram equalized image is 22.0417. Adaptive histogram equalization produced a more balanced result in terms of gray tone than histogram equalization, but the enhanced image was blurred and washed out especially at the edges. The EME is 4.6309. Alpha rooting enhanced the edge information resulting in an EME of 73.6503. But the resultant image suffers from over-graying which is characteristic of alpha rooting. Due to this, much of the extracted detail is not visually perceivable. Our Alpha Rooting Based Hybrid Procedure resulted in a balanced and visually better result. This procedure does not overemphasize any part of the image.

The method proposed in this paper, extracted the subtle details on the wings of the plane. The hidden contour lines and film grain in the background of the original image have also been deciphered but have not been over-enhanced. The parameters, α, b and γ, were varied to produce various qualities of enhancement. Figure 1(f) shows an image obtained by using parameters α = 0.7, b = 1.2, γ = 0.8, and a very high value of EME of 174.6505. The resulting image is also visually superior to the results of other techniques. Alpha Rooting Based hybrid contrast Enhancement Procedure also produced higher Tenengrad values than most of the conventional techniques which is an indicator to the higher level of sharpness and detail enhancement.

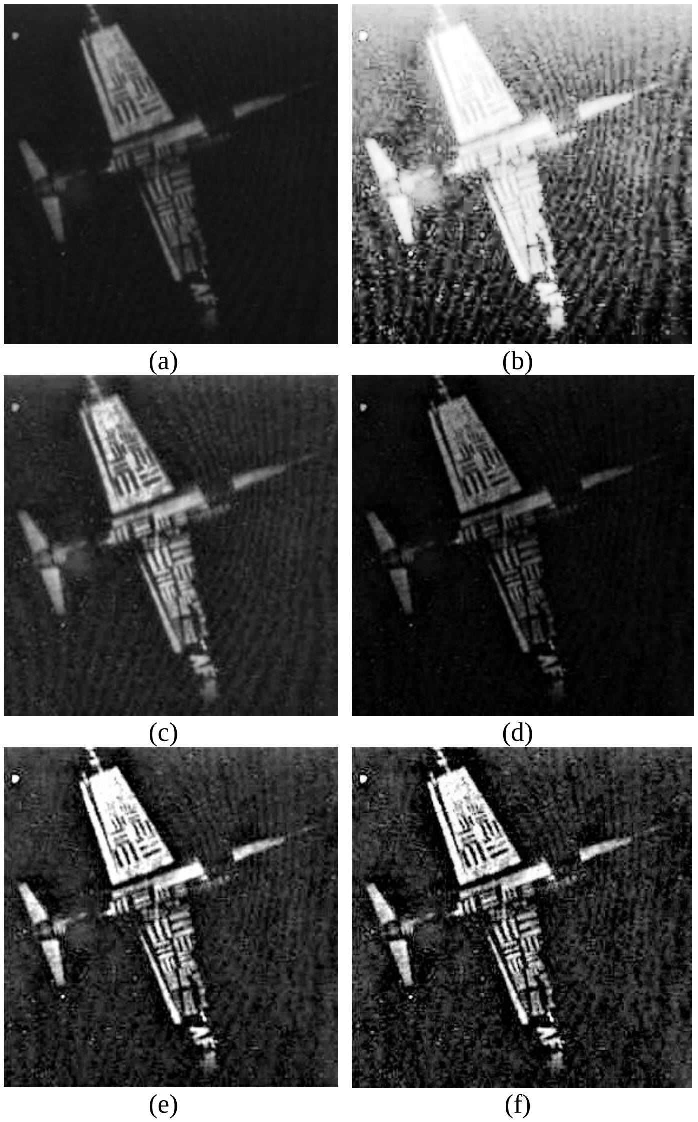


Fig. 1. U2 Image (a) Original EME = 3.7920, TEN = 3666 (b) Histogram Equalized EME = 22.0417, TEN = 21662 (c) Adaptive histogram Equalization, EME = 4.6309, TEN = 9886 (d) Alpha Rooting using $\alpha = 0.72$ EME = 73.6503, TEN = 5963 (e) Alpha Rooting Based Hybrid Procedure using parameters $\alpha= 0.78$, $b = 1.2$, $\gamma = 0.8$; EME = 90.8086, TEN = 20950. (f) Alpha Rooting Based Hybrid Procedure using parameters $\alpha= 0.7$, $b = 1.2$, $\gamma= 0.8$ EME = 174.6505, TEN = 24677.

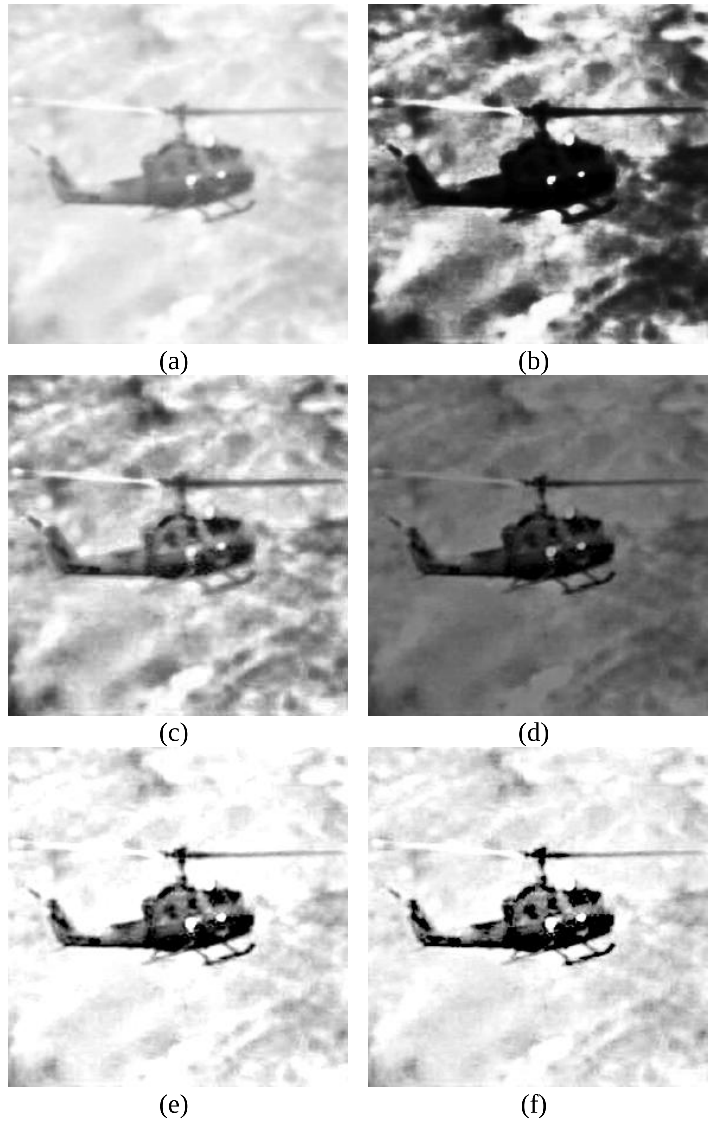


Fig. 2. Copter Image (a) Original EME = 7.0473, TEN = 2948 (b) Histogram Equalized EME = 13.0891, TEN = 17406 (c) Adaptive histogram Equalization, EME = 7.2747, TEN = 9487 (d) Alpha Rooting using $\alpha = 0.89$ EME = 13.3478, TEN = 3537 (e) Alpha Rooting Based Hybrid Procedure using parameters $\alpha = 0.83$, $b = 1.1$, $\gamma = 0.75$ EME = 15.7963, TEN = 17021 (f) Alpha Rooting Based Hybrid Procedure using parameters $\alpha = 0.79$, $b = 1.1$, $\gamma= 0.5$ EME = 19.5945, TEN = 17372.

The second image used for demonstration is the copter image. This was chosen because it has the interesting characteristic of a relatively dark central area and a lighter textured background. This difference in tone of the copter and the background makes the image rather difficult to enhance due to the tendency to enhance either the copter or the background but not both together. The original image has an EME of 7.0473. Histogram equalization resulted in complete loss of information on the copter. This demonstrates the dynamic range expansion problem suffered by histogram equalization. The EME of the histogram equalized image is 13.0891. In spite of this increase, the visual quality is very poor. Adaptive Histogram equalization resulted in an EME value of 7.2747 creating an image which is blurred in the foreground and background. Alpha Rooting produced an EME of 13.3478, again with the graying effect degraded the visual quality.

Our Alpha Rooting Based Hybrid Procedure produced good results by enhancing the copter and the background in a balanced manner. The information on the tail and the window of the copter has become discernible. Using parameters of enhancement $\alpha = 0.79$, $b = 1.1$, $\gamma= 0.5$ returned an excellent result with a more balanced enhancement which eliminated the limitations associated with the techniques of histogram equalization and alpha rooting. The enhanced image has a considerable EME value of 19.5945. Using parameters $\alpha = 0.83$, $b = 1.1$, $\gamma= 0.75$ produced a visually better enhancement on the copter and deciphered more detail from the copter. The

EME in this case is 15.7963. Thus our technique demonstrates the capability to enhance images having unbalanced distribution of tones. This demonstration makes the proposed algorithm fit to be applied to even such images which are difficult to enhance. This example also demonstrates the limitations of histogram equalization once more.

The next test image is the MiG image. This image is the direct opposite of the U2 image in tone. Whereas the U2 image had a dark tone, the MiG image has data points concentrated around the intensity level of 255. This characteristic makes the image difficult to enhance by techniques such as histogram equalization, as dynamic range expansion will drastically alter the tone of the image and produce unwanted artifacts. The original image has an extremely low EME of 0.00023.
Histogram equalization, as expected, produced a very dark image with a burnt out tone. This made the aircraft more of a silhouette and created ugly artifacts over the clouds in the background. Even though more background information is decipherable than the original image, the result is still noisy with poor visual quality.

Adaptive histogram equalization produced a better result, but the image is still not free from washed out appearance. The sharpness is poor and the background information as well as the plane is still fogged and poor in contrast. Alpha rooting rendered the entire image in a dark tone. Even the outline of the clouds which was visible in case of histogram equalization is lost. The result produced by the Alpha Rooting Based Hybrid Procedure is dramatic in terms of the visual quality.
This is recognition of how well the algorithm extracts obscured and hidden information. The strongest feature is the numbering on the forward fuselage (5063) which has become legible. In the original image we can hardly find the numbering. The nationality roundel and other markings on the tailfin, detail near the back jet nozzle, forward antenna and the fuel tanks under the wing are clearly visible.

Another striking feature is the clouds in the background. In the original image, the background is nothing more than a uniform gray screen which produces the delusion of a clear sky. This result shows the reliability and efficiency of the algorithm to be used for information extraction in real world enhancement applications. This particular example is also an epitome of how well the algorithm performs in case of light tone images.

The extension of this algorithm to the color domain returned dramatic results which also demonstrated the power of the algorithm to be applied to more practical real world applications like digital photography. The algorithm was implemented in the RGB color model. The color image is first decomposed into its red, green and blue components and the algorithm is applied independently on the three matrices. The processed red, green and blue components are merged together to get the resultant enhanced color image. The results obtained in color images also show a stupendous enhancement in the visual quality as well as a good increase in the EME and Tenengrad values in many images.

To demonstrate the effects of the algorithm on color images, we have deployed channel wise filtering only. This has been done with a view to preserve the basic nature of the algorithm and also for simplicity while demonstrating the algorithm operation on color images.

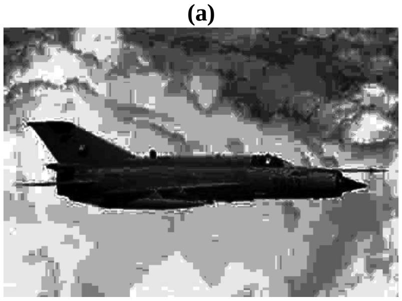
However, as this algorithm involves a non linear technique also, techniques such as multilevel smoothing [23] on HSI space can be employed along with empirical measures. Techniques employing logarithmic metrics [22] also exist which can be highly efficient in the present scenario. Albeit, here it has been a demonstration only and the algorithm was basically developed for operation on grayscale images. Hence for color images channel wise filtering on RGB space is followed to depict the spectacular effects of the basic algorithm on color images. Nevertheless, the most remarkable property worth mentioning is the ability of the algorithm to effectively enhance color images with poor lighting. Often in photography, the images acquired would be very dark in tone owing to poor and unbalanced lighting conditions or an inadequate adjustment of the camera. Photographs taken indoors, at night or with a bright light source in the background are most prone to this effect. This effect becomes more pronounced in the case of amateur photography.

Fig 4 (a) shows a digital photography image acquired in poor lighting conditions. The image is dark in tone and the features are shadowed in many places. Histogram equalization removed the darkness and shadowing of the image, but introduced a change of the color tone. It also brought about over brightening of the foreground which led to the loss of much detail. Adaptive histogram equalization resulted in many noisy artifacts on the enhanced image. The formation of a grayish tone is noticed on close inspection. The image is also not of a required quality in terms of sharpness. Alpha rooting increased the sharpness of the image, but as expected increased the dark tone. An attempt to enhance the image using Adobe® Photoshop® was done by applying +45 points contrast and +35 points brightness on the brightness/contrast slider. The result of this optimum enhancement is shown in fig 4 (e). Even though the overall brightness is increased, deterioration of the color tone due to appearance of a yellowish tint is noticeable.

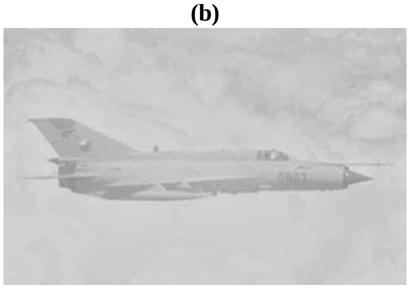
Our Alpha Rooting Based Hybrid Procedure brought about an excellent enhancement in terms of sharpness, contrast and brightness. The dark tone of the image is removed and the face as well as the background is clearly visible. The point worth noticing here is that while the contrast has been enhanced to a good extent, the true color tone of the image has also been greatly preserved in the enhanced image. This is observable from the skin and shirt color in the enhanced image in fig 4 (e). This property was not achieved in case of other conventional techniques. Also the background detail has been enhanced. The Alpha Rooting Based Hybrid Procedure enhanced image is also superior to the conventional enhancement techniques in terms of EME and Tenengrad values.

Alpha Rooting Based Hybrid Procedure resulted in an EME of 106.5448 as against 9.0119 of the original image. Tenengrad value also showed a significant increase from 6408 to 57708.

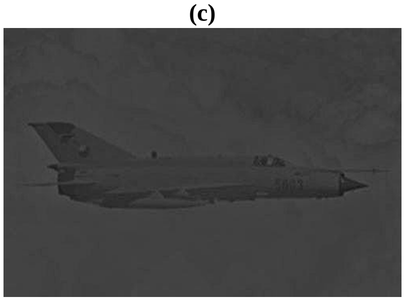
(a)



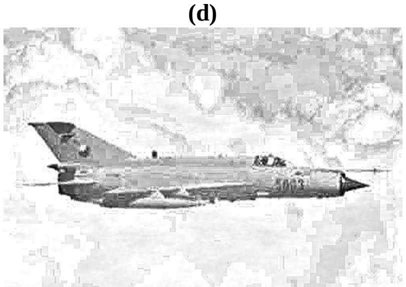
(b)



(c)



(d)



(e)

Fig. 3. MiG Image (a) Original- very dull and low contrast, note the plane itself is difficult to make out, EME = 0.00023 (b) Histogram Equalized - result unacceptably dark (c) Adaptive histogram equalization (d) Enhancement by Alpha Rooting using α = 0.78 (e) Alpha Rooting Based Hybrid Procedure using parameters α = 0.75, b = 1.1, γ= 2, EME = 0.7312 . Excellent enhancement, note the numbering (5063) in the forward position, tail markings, the antenna and underwing points in the aircraft and the clouds in the background- compare with original image.

In Figure 4 (f) the background as well as the foreground details of the image have become clearer (in the background, see the furniture on the deck, the awning, the name of the vessel and the deck lights; in the foreground, see the person, his spectacles, the reflection of the camera flash on the spectacles, the dark spots of perspiration and water on the author’s shirt and the pen in the pocket, in addition to the true color tone of the skin). This demonstrates that the proposed procedure for image enhancement can also be applied to natural digital photographic images affected by poor lighting which is a common phenomenon.

A table of optimum values of the parameters α, *b* and γ for some of the test images has been compiled. The corresponding EME values also have been given in Table 1. An evaluation of the EME values of images enhanced using Alpha Rooting Based Hybrid Procedure against the traditional techniques of histogram equalization; adaptive histogram equalization and alpha rooting are given in table 2.

The test images given in the table were chosen for their diversity in characteristics. As is evident from the table, the Alpha Rooting Based Hybrid Procedure presents a considerably higher EME than histogram equalization, adaptive histogram equalization and traditional alpha rooting in all the test images. This shows the stability and reliability of the algorithm in different qualities and types of images.

The performance of the algorithm in terms of the Tenengrad criteria also has been tested. The results have been furnished in table 3. As is evident from the table, the algorithm generates a considerable increase in Tenengrad in many images. This is indicative of the level of edge enhancement brought about by the algorithm.

The execution times of the algorithm for images of different dimensions have been evaluated. It can be found from Table 4 that the algorithm performs well in terms of the execution time on many images.

This new improved method developed by combining spatial and frequency domain techniques advocates the necessity of further study and exploration into the possibilities of combining elementary techniques of enhancement to achieve better results.

TABLE I
OPTIMUM VALUES OF PARAMETERS USED IN ALPHA ROOTING BASED HYBRID PROCEDURE FOR DIFFERENT IMAGES AND THE RESULTING EME VALUES.

Image	Form at	α	*b*	γ	EME	
					Origina l	Enhanced
U2 (Plane Top)	TIF	0.7	1.2	0.8	3.7920	174.6505
copter	TIF	0.79	1.1	0.5	7.0473	19.5945
MiG	JPG	0.75	1.1	2	0.00023	0.7312
pout	TIF	0.7	1.1	0.7	3.5180	86.7005
moon	TIF	0.8	1.3	0.8	24.3168	128.8940
cameraman	TIF	0.9	1.1	0.9	3.8325	40.6646
Peppers (color image)	PNG	0.88	1.0	0.8	0.2432	6.0218

TABLE II
COMPARISON OF EME VALUES OF DIFFERENT ENHANCEMENT METHODS FOR DIFFERENT IMAGES.

Image	Original	Histogram Equalization	Adaptive Histogram Equalization	Alpha Rooting	Alpha Rooting Based Hybrid Procedure
U2	3.7920	22.0417	4.6309	73.6503	174.65
copter	7.0473	13.0891	7.2747	13.3478	19.5945
pout	3.5180	27.181	3.7290	8.7233	86.7005
moon	24.317	27.251	9.9033	126.729	128.894
camera man	3.8325	14.072	6.4175	23.1616	40.6646
peppers (color)	0.2432	1.0063	0.8774	5.6773	6.0218

TABLE III
COMPARISON OF TENENGRAD VALUES OF DIFFERENT ENHANCEMENT METHODS FOR DIFFERENT IMAGES. OPTIMUM PARAMETERS USED FOR ALPHA ROOTING BASED HYBRID PROCEDURE.

Image	Original	Histogram Equalization	Adaptive Histogram Equalization	Alpha Rooting	Alpha Rooting Based Hybrid Procedure
U2	3666	21662	9886	5936	24677
copter	2948	17406	9487	3537	17372
pout	2173	14048	9061	3460	28663
moon	11282	24009	15026	12875	40736
cameraman	10391	13340	20125	10667	17813
Peppers (color)	11282	24009	20004	12875	40736

TABLE IV
EXECUTION TIME OF ALPHA ROOTING BASED HYBRID PROCEDURE ON COMPUTER SYSTEM WITH 512 MB RAM AND 2.8 GHZ DUAL CORE PROCESSOR.

Image	Format	Dimension	Execution Time of Alpha Rooting Based Hybrid Procedure (in seconds)
U2 (Plane	TIF	289 x 289	1.1095
copter	TIF	287 x 287	1.1492
MiG	JPE	312 x 500	1.8752
moon	TIF	537 x 358	2.6803
Lifting body	PNG	512 x 512	4.0686
peppers	PNG	512 x 384 x 3	5.4722

VI. CONCLUSION

In this paper we elucidated an Alpha Rooting Based Hybrid Procedure for image enhancement which is free of the conventional limitations associated with the transform domain image enhancement techniques. The improvement is accomplished by complementing the transform domain technique of alpha rooting with the spatial domain techniques. The procedure, initially directed at alleviating the drawbacks of conventional alpha rooting, however evolved into a powerful parameter based enhancement technique.

The striking feature of this procedure is that it produces highly balanced and visually appealing results for a diversity of images with different qualities of contrast and edge information. The improvement in image enhancement is particularly effective in the case of very low contrast images. The extent of edge information can be greatly enhanced by this algorithm which renders it suitable for detail extraction. The extension of the algorithm to the color domain also yielded excellent results.

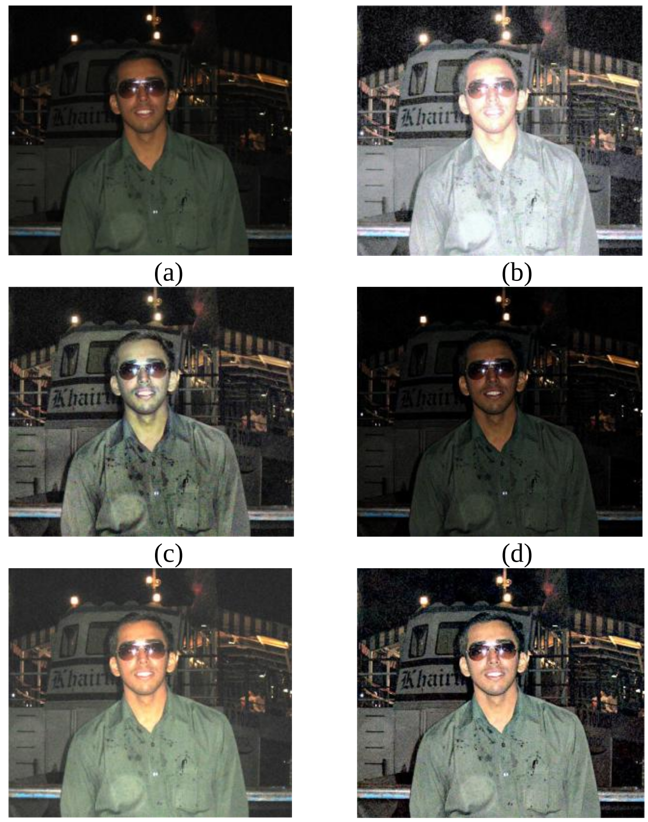


Fig. 4. Color Image of one of the authors acquired by a Canon DIGITAL IXUS 60 digital camera in poor and unbalanced lighting conditions (a) Original – dark in tone and shadowed EME = 9.0119, TEN = 6408 (b) Histogram Equalized – Note drastic change in color tone. EME = 31.7967, TEN = 55174 (c) Adaptive histogram Equalization, EME = 10.2865, TEN = 39021 (d) Alpha Rooting using $\alpha = 0.82$ EME = 54.667, TEN = 8702 (e) Adobe® Photoshop® 7.0 generated enhancement with +45 points contrast and +35 points brightness applied EME = 2.6509, TEN = 18783 (f) Alpha Rooting Based Hybrid Procedure using parameters $\alpha = 0.89$, $b = 1.3$, $\gamma = 0.6$ EME = 106.5448, TEN = 57708 – Note preservation of true color tone of the skin and enhancement of background detail. The dark shadowed tone of the original image is also removed.

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