

Image Enhancement by Adaptive Power-Law Transformations

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ABSTRACT - Normally the quality of an image is improved by enhancing contrast and sharpness. The enhancement of contrast and sharpening of an image with a single function is a complex task. In real-time imaging, many complex scenes require local contrast improvements that should bring details to the best possible visibility of the image. However, local enhancement methods mainly suffer from ringing artefacts and noise over-enhancement. In this paper, we present a new adaptive spatial domain contrast and sharpness enhancement method, in which modified power-law transformations function is applied. Our algorithm controls perceived sharpness/smoothness, ringing artefacts (contrast) and noise, resulting in a good balance between visibility of details and non-disturbance of artefacts by controlled parameters. Its advantage over the standard power-law transformations is to enhance sharpness/smoothness and contrast with a single function by appropriate choice of control parameters. Sharpness control parameter can be also used to smoothen the image by taking the negative value of sharpness parameter. This method can be applied both to grey scale and colour images like Gamma Correction (GC). In the case of colour images, it is applied to each channel R, G and B separately.

Index Terms - Adaptive, power-law, Image enhancement, Contrast, Transformations, Image sharpening, Artefact.

I. INTRODUCTION

Image denoising, enhancement and sharpening are important operations in the general fields of image processing and computer vision. Its main objective is to improve the quality of an image for visual perception by human beings. It is also used for low level vision applications. It is a task in which the set of pixel values of one image is transformed to a new set of pixel values so that the new image formed is visually pleasing and is also more suitable for analysis. Machine vision has many important applications of digital images that are captured in low contrast conditions. These images often encounter serious problems in recognition systems. Hence contrast enhancement is an important part of image processing. How to enhance the contrast is a vital factor in image recognition problem, and many methods for improving the image quality in contrast have been proposed.

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Histogram equalization [1] is one of the most well-known methods for contrast enhancement in images with poor intensity distribution. Retinex [2] (retina and cortex) is an important model of human vision system and many methods based on it have been developed. The single scale retinex (SSR) method and the multistage retinex (MSR) are the most useful methods. MSR can provide better tonal rendition than SSR. Edge enhancement is also important in contrast enhancement. Multiscale edge enhancement using the wavelet transform [3] is a way to enhance the contrast by enhancing the edges in scale space since edges play a fundamental role in image understanding. Curvelet transformation is well-adapted to represent images containing edges, it works well for edge enhancement [4]. Curvelet coefficients can be modified in order to enhance edges in an image. It can preserve edges better than wavelet transformation.

In medical image applications contrast enhancement are important due to the fact that visual examination of medical images is essential in the diagnosis of many diseases such as chest radiography and mammography [5], [6]. The image contrast is inherently low due to the small differences in the X-ray attenuation coefficients. The problem is further complicated if an image consists of several regions with different X-ray attenuation characteristics. For example, in chest radiography, the mediastinum and the lung field have different exposures. It is usually desirable to enhance the details in both regions simultaneously. Thus, a considerable amount of research has focused on this subject. The development of enhancement algorithms is based on some visual principles. It is known that the human eye is sensitive to high-frequency signals. Although details usually correspond to high-frequency signals, their visibility becomes low when they are embedded in strong low-frequency background signals. Thus, properly amplifying the high-frequency components will improve visual perception and help diagnosis.

For real-time imaging in surveillance applications, visibility of details is obtained amongst others via video signal enhancement that should accommodate for the widely varying light conditions and versatility of scenes with nonideal luminance distribution. The primary task of these algorithms is to improve perception, sharpness and contrast and bring visibility of details in all parts of the scene to the

highest possible level. In real-time surveillance applications, almost no human interaction occurs for the enhancement (autonomous processing), while the computation complexity must remain low, thereby posing a significant problem. A possible solution is to apply advanced contrast control. Almost all current algorithms used in surveillance systems belong to the group of the global methods, where one transformation is applied to all pixels of the input image. However, there are often more complex situations, where contrast can be poor in some parts of the image, but adequate in other parts, or when overall contrast is good but local contrast is low. In these cases, locally-adaptive contrast enhancement will provide significant advantages. Kuroda [7] proposed an algorithm for real-time adaptive image enhancement, but its application and capabilities are limited. Chang *et al.* [8] observed that image enhancement with contrast gain which is constant or inversely proportional to the Local Standard Deviation (LSD) produces either ringing artefacts or noise over enhancement due to the use of too large contrast gains in regions with high and low spatial activities. They developed a new method based on extending Hunt's image model [9] in which gain is a non-linear function of LSD. Although promising, this approach has very high complexity making it inappropriate for real-time implementation. In addition, no general rule is given to determine the optimal window size, which anyhow varies from point to point. This problem led to multiscale methods. Boccignone [10] proposed to measure contrast at multiple resolutions generated through anisotropic diffusion. Once local contrast has been estimated across an optimal range of scales, its value is used to enhance the initial image. Again, computation time and complexity are obstacles for employing it in a real-time system. Narendra and Fitch [11] presented a real-time high frequency enhancement scheme, in which they amplified medium and higher frequencies in the image by gain that is inversely proportional to the LSD. Schutte [12] introduced a multi-window extension of this technique and showed how the window sizes should be chosen. Prevention of excessive noise amplification is included, but the method is not sufficient in case a higher noise level is present or higher amplification factors are used. At the same time, a mechanism for the ringing and artefact suppression is not given.

Most of the techniques such as contrast stretching, slicing, histogram equalization for image enhancement are based on grey scale images. The generalization of these techniques to color images is not straight forward. Unlike grey scale images, there are some factors in color images like hue which need to be properly taken care of for enhancement. Hue, saturation and intensity are the attributes of color [1]. Hue is that attribute of a color which decides what kind of color it is, i.e., a red or an orange. One needs to improve the visual quality of an image without distorting attributes of color of the image. Several algorithms are available for

contrast enhancement in grey scale images, which change the grey values of pixels depending on the criteria for enhancement without taking care about the colour attributes like hue. On the other hand, colour image enhancement must preserve the three attributes of colour images. Sarif Kumar Naik and C. A. Murthy [13] proposed a colour image hue preserving enhancement technique where hue unaltered transformation of the image data from RGB space to other colour spaces such as LHS, HSI, YIQ, HSV, etc. is done. Strickland *et al.* [14] proposed an enhancement scheme based on the fact that objects can exhibit variation in color saturation with little or no corresponding luminance variation. Thomas *et al.* [15] proposed an improvement over this method by considering the correlation between the luminance and saturation components of the image locally. Toet [16] extended Strickland's method to incorporate all spherical frequency components by representing the original luminance and saturation components of a colour image at multiple spatial scales. Four different techniques of enhancement, mainly applicable in satellite images, based on "decorrelation stretching" [17] and rationing [18] of data from different channels are proposed by Gillespie *et al.* Gupta *et al.* proposed a hue preserving contrast stretching scheme for a class of colour images in [19].

This paper is organized as follows. In Section II, linear contrast enhancement transformations methods are described. In Section III, an Adaptive Power-law Transformation is described as proposed algorithm. Section IV provides the experimental results comparing with other methods and some output results. Section V contains conclusion.

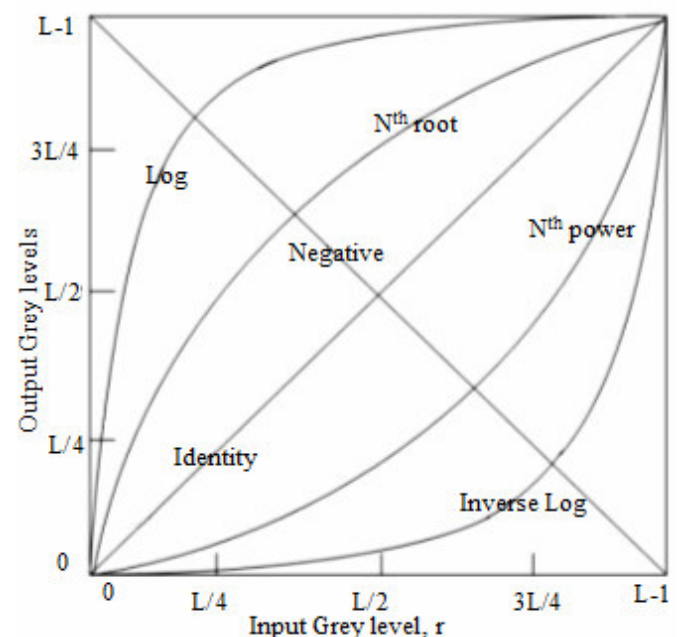


Fig.1: Plot of various transformation functions

II. IMAGE TRANSFORMATIONS

Image enhancement simply means, transforming an image I into image O using T , where T is the transformation function. The values of pixels in images I and O are denoted by r and s , respectively. As said, the pixel values r and s are related by the expression

$$s = T(r) \quad (1)$$

where T maps a pixel value r into an another pixel value s . The results of this transformation are mapped into the grey scale range as we are dealing here only with grey scale digital images. So, the results are mapped into the range $[0, L-1]$, where $L=2^k$, k being the number of bits in the image being considered. So, for instance, for an 8-bit image the range of pixel values will be $[0, 255]$.

There are three basic types of f (transformation functions that are used frequently in image enhancement. They are,

- Linear,
- Logarithmic,
- Power-Law.

The transformation map plot shown in Fig.1 depicts various curves that fall into the above three types of enhancement techniques.

A. Log Transformations

The log transformation curve shown in Fig. 1, is given by the expression

$$s = c \log(1 + r) \quad (2)$$

where c is a constant and it is assumed that $r \geq 0$. The shape of the log curve in Fig. 1 tells that this transformation maps a narrow range of low-level grey scale intensities into a wider range of output values. Similarly it maps the wide range of high-level grey scale intensities into a narrow range of high level output values. The opposite of this applies for inverse-log transform. This transform is used to expand values of dark pixels and compress values of bright pixels. It seems to control only the brightness, means that it gives either to increase or decrease of all outputs only depending on the different values of c and r . It cannot control the contrast adjustment and image sharpness.

B. Power-Law Transformations

The n th power and n th root curves shown in Fig. 1 can be given by the expression,

$$s = cr^{\gamma} \quad (3)$$

This transformation function is also called as *Gamma Correction* (GC). For various values of γ different levels of enhancements can be obtained. We know that different display monitors display images at different intensities and clarity. That means, every monitor has built-in Gamma correction in it with certain Gamma ranges and so a good monitor automatically corrects all the images displayed on it for the best contrast to give user the best experience. It also gives the overall increase or decrease outputs depending on the values of c and γ without contrast and sharpness control.

III. ADAPTIVE POWER LAW TRANSFORMATIONS

The proposed Adaptive Power-law Transformations is given by the following expression;

$$s = c(1 + kd)r^{\gamma(1-kd)} \quad (4)$$

where s is the transformed enhanced output pixel value of image O , r is the input pixel of the image I , c , γ and k are constants which control the brightness, contrast and sharpness/smoothness of O .

$$d = r - \bar{x} \quad (5)$$

where \bar{x} is the local mean of the input image within a window of size $w \times w$ with r as centre at (i, j) of the window.

Both the input image I and output image O are in the range of 0 and 1.

If $k=0$, then it is equivalent to the GC and if $k \neq 0$, then the three parameters take different roles of varying different levels of enhancement of the output image unlike GC. There will be three controls depending on the different parameters such as brightness, contrast and sharpness/ smoothness of the output image.

A. Brightness

The parameter c controls the brightness of the image just like c in Gamma Correction (GC) function in Equation 3. Depending on the different values of c , we can vary various levels of brightness keeping the other values at constant. As the value of c increases, the brightness increases and vice versa. The graphical representation of various brightness of different values of c is shown in Fig. 2.

B. Contrast Stretching

The parameter γ is the contrast stretching factor. If $k=0$ there will be overall increase or decrease in the brightness of output image O like Gamma Correction Equation 3 for

different values of γ . If $k \neq 0$ there will be various levels of contrast stretching unlike Gamma Correction. k may be positive or negative according to our requirement

The various contrast adjustment levels depend upon the value of d for k at positive constant. Those pixel whose values are below the local mean \bar{x} , i.e. $d < 0$ will give higher value of $\gamma(1-kd)$ and lower value of $c(1+kd)$ resulting lower transformed value of s . Those pixels whose values are greater than the local mean \bar{x} , i.e. $d > 0$ will give lower value of $\gamma(1-kd)$ and higher value of $c(1+kd)$ resulting higher transformed value of s . If k is negative constant, the result will be opposite. Depending on the values of γ , there will be various levels of enhancement unlike GC keeping the others parameters at constant. Thus in this transformation technique, there may not be over all increase or decrease at the output values. The value of d varies the level of contrast adjustment with the of γ . In Fig.3 shows the various levels of contrast adjustment at different values of γ .

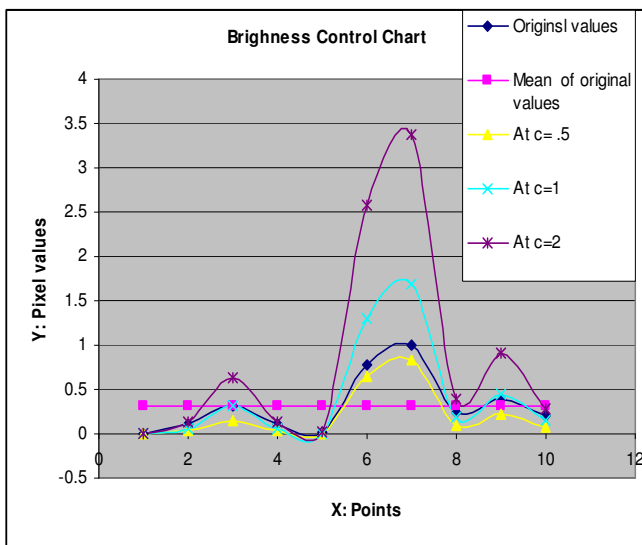


Fig. 2: Plot of different levels of brightness at different values of c keeping γ and k at constant value..

C. Sharpening/Smoothing

Image sharpening is to highlight fine details in an image or to enhance detail that has been blurred, either in error or as a natural effect of a particular method of image acquisition. Contrast stretching between low and high frequency pixels, edge portion of an image can be more distinct. The parameter γ can adjust the contrast stretching of the output image O depending not only on the value of d , but also the value of k . The mode of adjustment depends upon the sign of k . If k is positive the degree of contrast stretching will depend on the different values of k . The more the value of k , the more contrast stretching, resulting in more sharpened image. If k is negative there will be reverse contrast stretching.

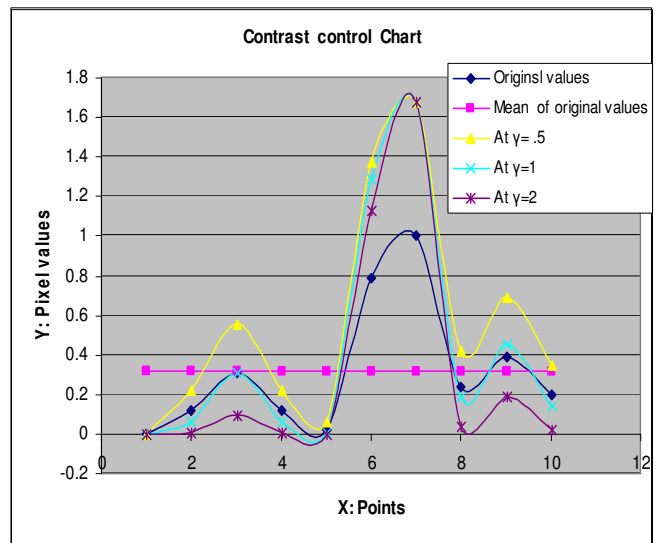


Fig.3: Plot of different levels of contrast stretching at different values of γ keeping c and k at constant value.

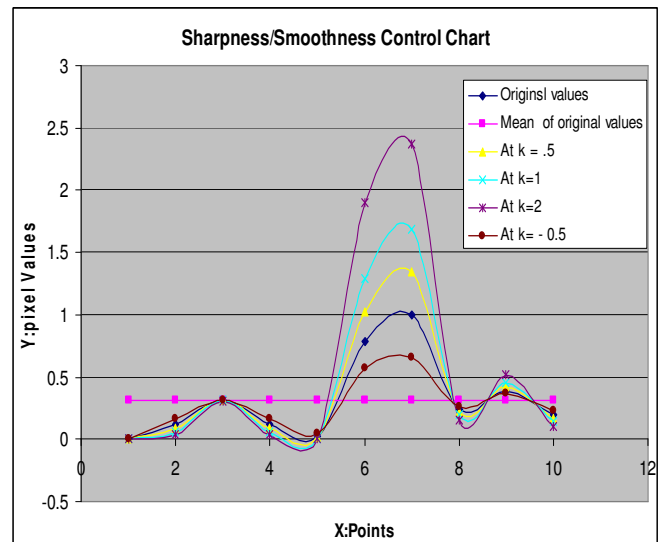


Fig.4: Plot of different levels of sharpness/ smoothness keeping γ and c at constant value.

When $k < 0$ those pixels whose values are below the local mean \bar{x} , i.e. $d < 0$ will give lower value of $\gamma(1-kd)$ and higher value of $c(1+kd)$ resulting higher value of s while those pixels whose values are greater than local mean give higher value of $\gamma(1-kd)$ and lower value of $c(1+kd)$ resulting in lower value of s . This means all pixels below respective local mean will rise up and pixels upper the local mean will lower down by converging to a new mean resulting in a smooth image. If k is much negative there will be a reverse values between lower and higher pixel forming a reversed pixel image like negative image at the edge portion. Fig.4 shows the graphical representation of difference levels of sharpness/smoothness at different values of k . Fig.5 shows smoothness with $k = -1$, $k = -5$ and $k = -10$.



Fig.5: Image smoothness (a) original Bele (254x384), (b) smoothness with $c = 2$, $\gamma = 1.5$ and $k = -1$ (c) smoothness at $c=2, \gamma=1.5$ and $k = - 5$ (d) smoothness at $c = 2,$ $\gamma = 1.5$ and $k = -10$

IV. EXPERIMENTAL RESULTS

Experiment was carried out using MathLab 7.2. The proposed technique was tested on different types of images including medical images. For the comparison, standard power-law transformations, log-transformations, histogram equalisation and Laplacian sharpening techniques were used. Comparison was done visually. Local window size (5×5) was chosen in our experimentation.

We considered three aspects of enhancement brightness, contrast stretching and image sharpening/smoothness controls. Image brightness control is common process in all methods and hence it was not considered. Only contrast stretching and sharpness/smoothness were considered.

A. Contrast stretching

The parameter γ controls the contrast adjustment. The condition $0 < \gamma \leq 1$ produces over all contrast enhancement resulting a brightened image. This condition may be applied for dark images to produce brightened images. Fig.6 shows the visual comparison of this method with GC and Histogram equalisation for both grey scale and colour images.

Here Histogram Equalisation and GC method give an over brighten images while the proposed algorithm gives a well brighten as well as more sharpened image. This condition is suitable for under exposed images.

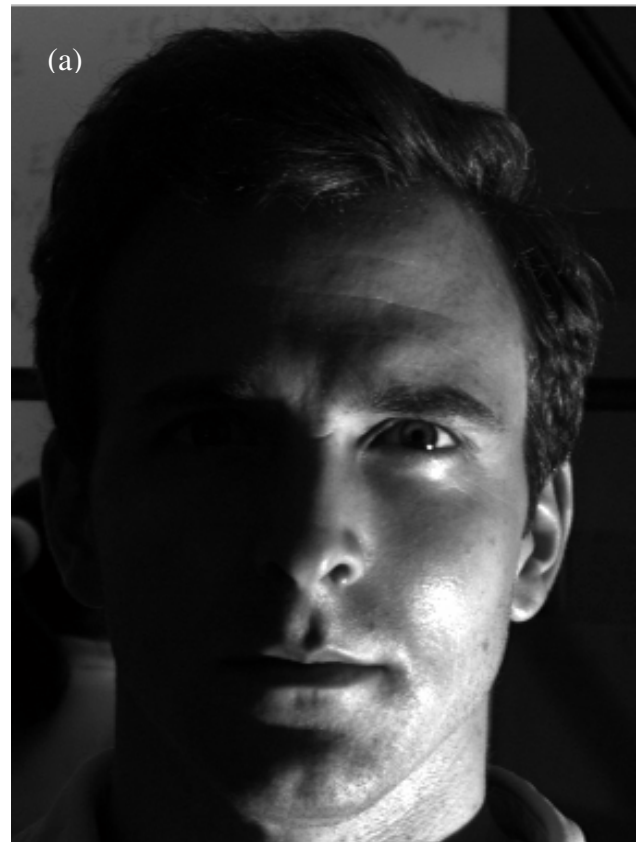
If $\gamma > 1$, there will be contrast stretching in such a way that those pixels which are lower than local mean will be stretched towards black while others are stretched towards white resulting a good looking image for bright images. Fig.9 shows the contrast stretched output image with parameters $c=1.5$, $\gamma=1.5$ and $k=2$.

B. Sharpening/Smoothing

The parameter k controls the sharpness/ smoothness of the input images. If $k > 0$ there will be sharpening effect while $k < 0$ there will be smoothing effect. If $k=0$, result is same as that of GC. The more the value of k , the more sharpening, while the more negative value of k resulted the more smoothness of the image. Fig.7 shows the comparison of results by Laplacian method and proposed algorithm at $c=2$, $\gamma=2$ and $k=3$. From this result, we observe that Laplacian method gave sharpened images while proposed algorithm gives more contrast and sharpened images.

From the experimental results we can observe that the proposed system performs better than other methods on the whole. This is due to the fact that our proposed algorithm considers the dual characteristic of enhancement like contrast stretching and sharpening/ smoothing, while other methods

have only one characteristic. Fig. (8-10) shows the results of the proposed algorithm.



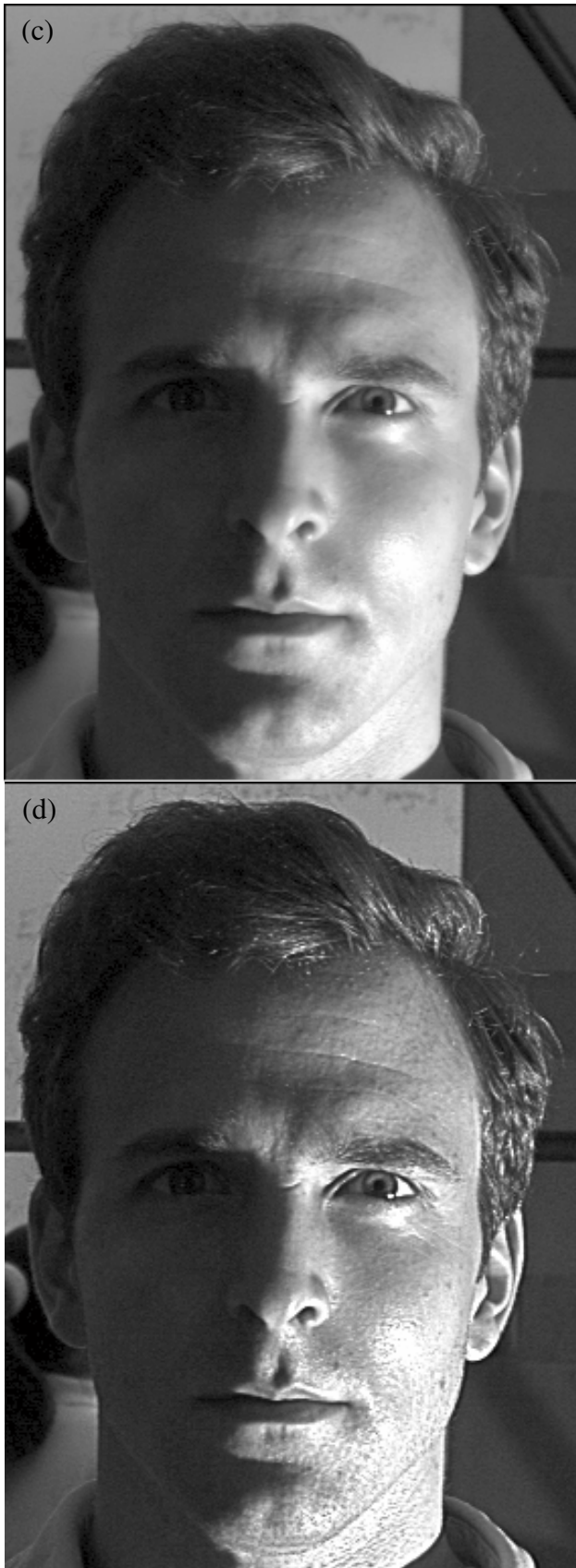


Fig.6: Contrast enhancement control: (a) original man (288x386), (b) result of Histogram, (c) result of GC at $c = 1, \gamma = 0.5$ (d) result of proposed algorithm at $c = 1, \gamma = 0.5$ and $k = 2$.

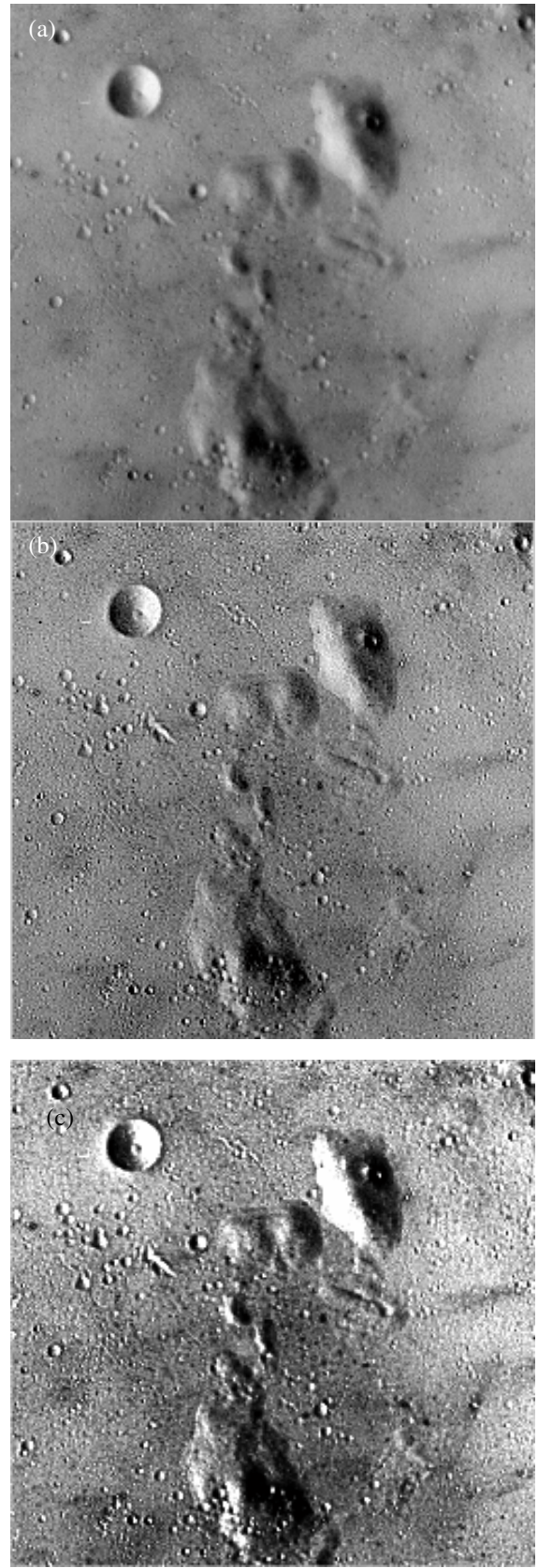


Fig.7: Sharpness Control result (a) original moon surface (256x256), (b) result of Laplacian method (3x3) (c) result of proposed algorithm(5x5) at $c=2, \gamma=2$ and $k=3$.

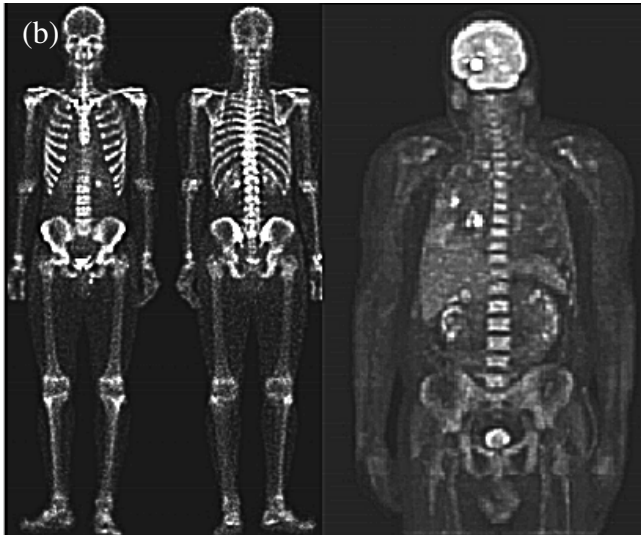
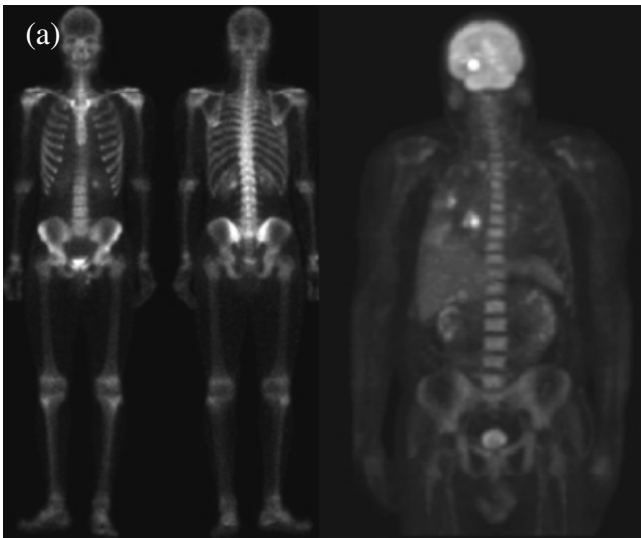


Fig.8: Output result (a) original X-ray (269x229), (b) result by proposed algorithm at $c = 1$, $\gamma = 0.8$ and $k = 10$.

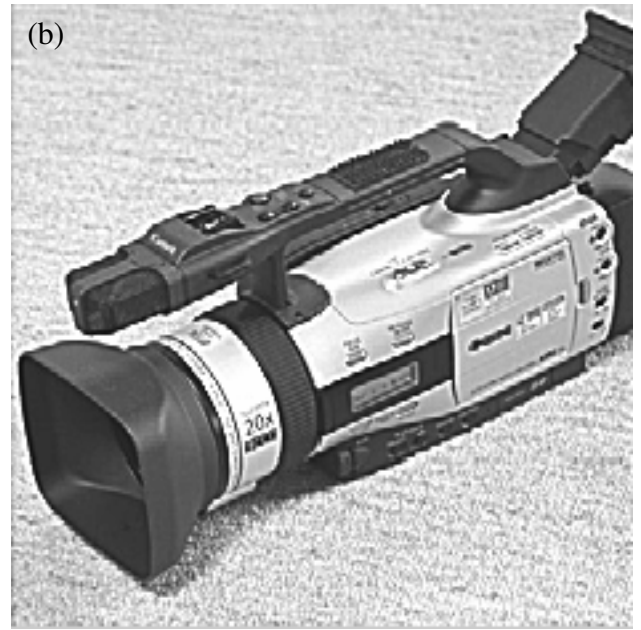
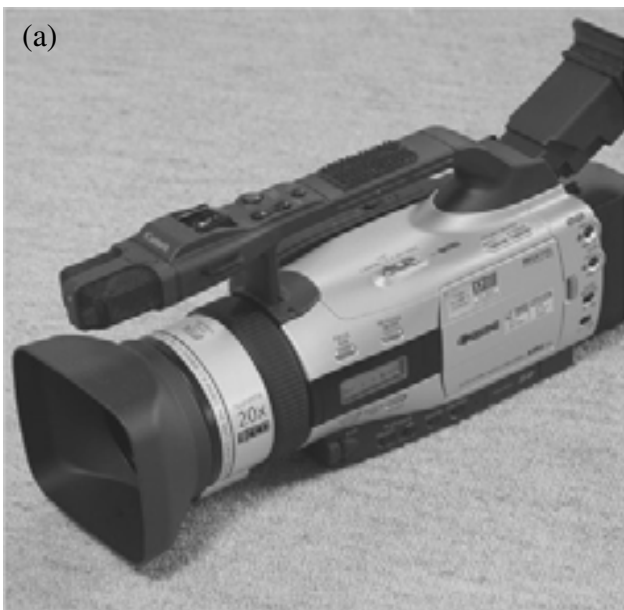


Fig.9: Output result (a) original camera (239x252), (b) result by proposed algorithm with $c=1.5$, $\gamma=1.5$ and $k=2$.

V. CONCLUSION

Power-law Transformations, Log Transformations, Laplacian sharpening and Histogram Equalization are well-known image enhancement techniques. These conventional techniques suffer from noise over-enhancement, ringing artifacts and over-exposure. In this paper, we present a new Adaptive Power-law Transformations algorithm to overcome these problems. We propose a mathematical model for the Adaptive Power-law Transformations having dual characteristics of contrast stretching and sharpening/smoothing. Based on this model, we control the locally adaptive level for enhancing an input image based on the spatial pixel values within the region. There are three parameters in our model which could be chosen to meet different requirements. These parameters control brightness, contrast stretching and sharpness/smoothness of an image so that we could obtain our desired output image. The main contribution of this algorithm is to enhance an image both in contrast as well as sharpness/smoothness resulting in a more pleasing image with a single mathematical model.

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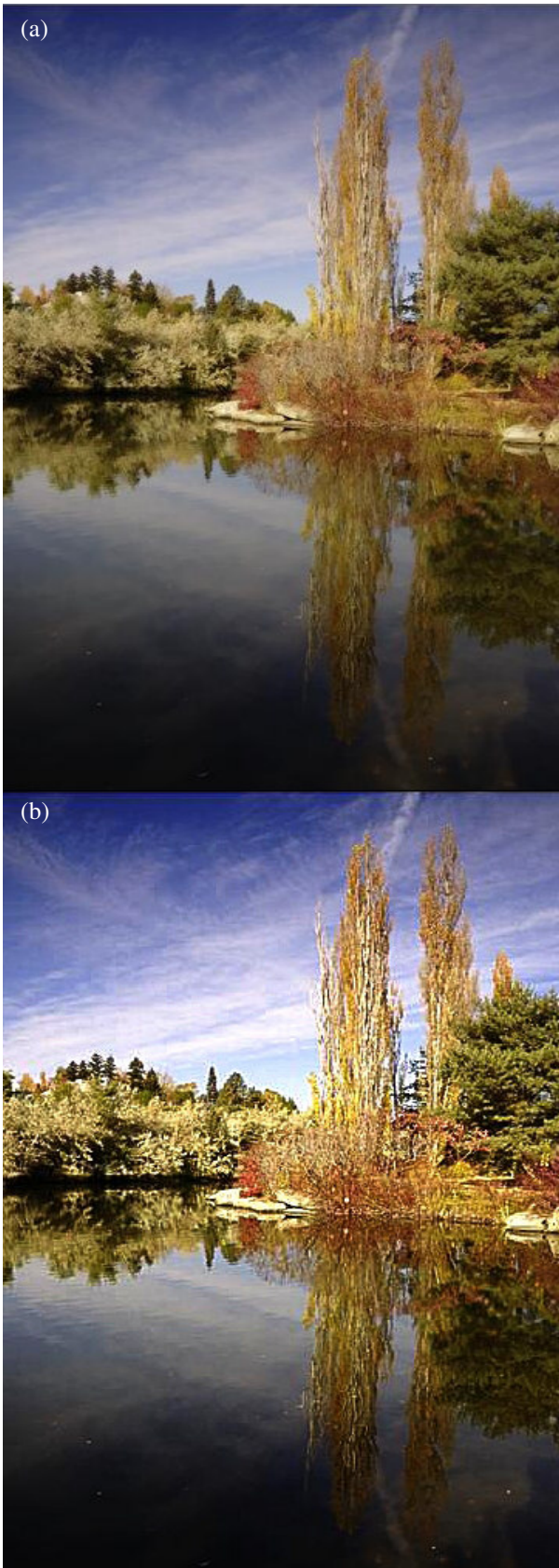


Fig.10: Output result (a) original scene (372x560), (b) Result by proposed algorithm at $c=1.3$, $\gamma=1.2$ and $k=1.4$.