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Automatic Enhancement of Low Contrast Images using SMRT

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Abstract— Contrast enhancement has an important role in Image processing applications as it extracts useful information from an image. Enhancement of low contrast images is usually done in the spatial domain as a preprocessing step, followed by image processing methods in the transform domain. This paper proposes a simple, yet powerful image enhancement technique in transform domain for addressing low contrast and brightness problems in gray-scale and color images. It uses SMRT to automatically change the statistical parameters such as mean & standard deviation by controlling brightness and contrast.

Index Terms— Image Enhancement, Sequency based Mapped Real Transform(SMRT), Brightness, Contrast, Scaling factor, SDME, Histogram Equalization.

1 INTRODUCTION

IMAGE enhancement is usually a preprocessing step in many image processing applications. Its aim is to accentuate relevant image features that are difficult to visualize under normal viewing conditions and thereby facilitating more accurate image analysis [1]. Various reasons for poor image quality may be due to poor illumination, lack of dynamic range in image sensor or wrong settings of lens aperture at the time of image acquisition. Sometimes, radiographic image details are lost due to machine limitations or noise artifacts.

Visual appearance of an image can be significantly improved by brightness variation and contrast stretching. Brightness of an image can be varied by changing its mean without changing histogram. Contrast can be determined from its dynamic range, defined as the difference between highest and lowest intensity level present in the image. Contrast enhancement stretches the histogram to perceive more details, normally not visible. Hence histogram stretching can be used to enhance low contrast images.

Many techniques for increasing contrast have been proposed in the past and these can be classified into two categories: spatial domain methods and transform domain methods. Spatial domain techniques perform direct manipulation of pixels in an image and can be carried out on the whole image or on a local region selected on the basis of image statistics. Such techniques include histogram processing, image averaging, sharpening edges or contours and nonlinear filtering [2], [3], [4], [5].

In transform domain techniques, transform such as DFT, DCT, DWT of the image is computed first. The transform coefficients are then manipulated appropriately and inverse transform is found to obtain the enhanced image [6], [7], [8], [9].

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Most common and simple image enhancement technique is contrast stretching and can be achieved by processing its histogram. It is usually done in the spatial domain by way of histogram stretching, equalization or matching. Histogram equalization employs a monotonic, non-linear mapping that reassigns the intensity values of pixels in the input image and produces an image with uniform histogram. Histogram stretching spreads the histogram to a larger range by applying a piecewise linear function while histogram matching produces an image with pre specified histogram.

Instead of processing the histogram directly, statistical parameters such as mean and Standard Deviation (SD) can be used for modifying the image. Mean is a measure of average gray level intensity of the image and SD is a measure of the histogram stretch.

Most of the image enhancement techniques are performed in the spatial-domain. But for efficient storage and transmission, images are being represented in the compressed format [10], [11] using transform domain. If all the image processing tasks are performed in the same transform domain, the processing will be computationally efficient. Hence, it is important to develop image enhancement techniques in the transform domain.

This paper proposes a way to improve the contrast and brightness of an image using transform domain techniques. Statistical parameters such as mean and SD can be varied by modifying SMRT coefficients to improve the brightness and contrast. Hence a method is proposed, which automatically adjusts the image brightness and contrast to optimum levels by modifying the SMRT coefficients appropriately by utilizing full dynamic range of the histogram. A comparison between the proposed method and Histogram Equalization is also performed.

2 SMRT

MRT coefficients, $Y_{k_1k_2}^{(p)}$ of an image $x_{n_1n_2}, 0 \leq n_1, n_2 \leq N-1$ is expressed [12] as

$$Y_{k_1 k_2}^{(p)} = \sum_{\forall (n_1,n_2)|z=p} x_{n_1,n_2} - \sum_{\forall (n_1,n_2)|z=p+M} x_{n_1,n_2}$$

$$\text{for } 0 \le k_1, k_2 \le N-1,\ 0 \le p \le M-1 \ \&\ M = N/2. \quad (1)$$
where $z = ((n_1 k_1 + n_2 k_2))_N$

2-D MRT maps an $N \times N$ matrix into M matrices of the same size. Thus MRT in the raw form will have $N^3/2$ coefficients and is highly redundant. Unique MRT (UMRT) [13], [14] is developed to remove redundant elements present in MRT representation and arranges the N^2 unique coefficients in an $N \times N$ matrix. Using SMRT [15], the N^2 unique MRT coefficients are arranged in the order of sequency along horizontal, vertical and diagonal directions and are represented by matrix S.

The first coefficient, S(0,0), of the SMRT matrix is found in terms of the input image as sum of all image pixel values and is called dc coefficient. This value gives an indication of the image mean and holds most of the image energy. The remaining (N^2-1) coefficients represent the intensity values of the image pixels in various patterns and can be termed as ac coefficients.

3 SMRT BASED IMAGE ENHANCEMENT

In this method, dc as well as ac SMRT coefficients of the image are scaled using scaling factors c_{dc} and c_{ac} respectively. Experimental studies show that if c_{dc}>1 the histogram shifts forward and if it is less than one, the histogram shifts backward without changing its shape. Hence, the brightness of the image can be increased as shown in Fig. 1 by scaling, S(0,0) without any change in contrast.

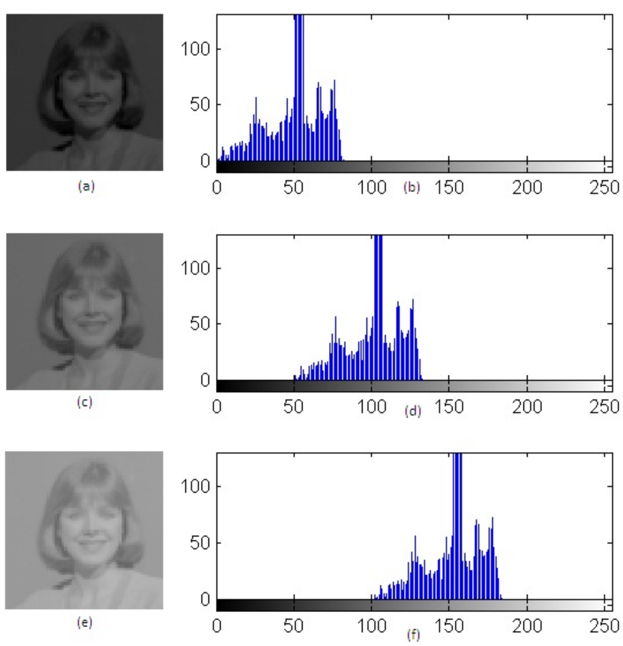

Fig.1. Images and their histograms (a)&(b) Original (c)&(d) dc SMRT coefficient scaled with c_{dc}=2 (e)&(f) dc SMRT coefficient scaled with c_{dc}=3

Experimental studies show that the contrast and SD of an image can be changed by scaling ac SMRT coefficients while preserving the image mean. The histogram gets stretched or compressed when the scaling factor c_{ac} is greater or less than one and thereby modifying the image contrast. Fig.2 shows changes in contrast of the image and the corresponding histograms for different values of c_{ac}.

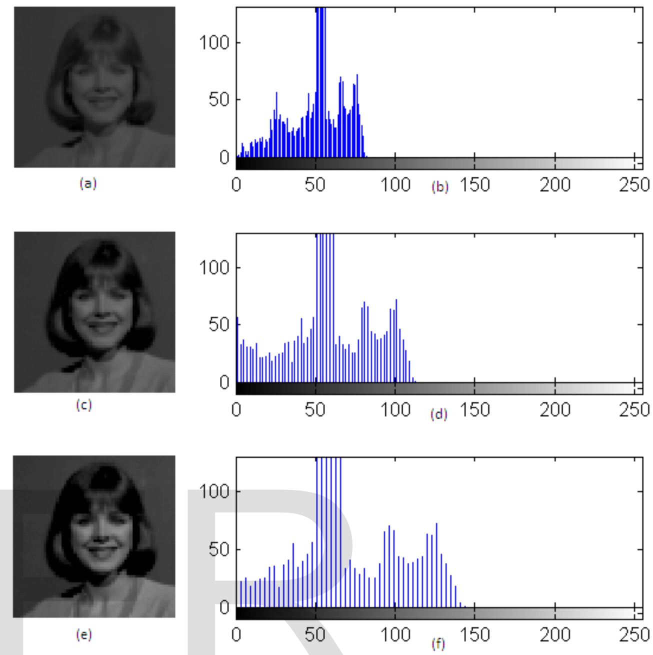

Fig.2. Images and their histograms (a)&(b) Original (c)&(d) ac SMRT coefficients scaled with c_{ac}=2 (e)&(f) ac SMRT coefficients scaled with c_{ac}=3

The brightness and contrast adjusted SMRT matrix can be expressed as

$$\tilde{S}(i,j) = \begin{cases} c_{dc}\, S(i,j), & if\ i=j=o \\ c_{ac}\, S(i,j), & otherwise \end{cases} \quad (2)$$

When c_{ac} is made higher and higher, the histogram stretches and extends to both ends. When this value is much higher, the histogram gets split and departs to the two ends. Finally it becomes a black and white image.

For maximum enhancement, the image mean or center of the image histogram can first be brought to the center of the range of the histogram (for n bit image representation, $2^{(n-1)}$ is the center of range of the histogram) by scaling S(0,0). Once brightness is adjusted, contrast can be maximized by scaling ac SMRT coefficients

3.1 Brightness Variations using dc SMRT Coefficient

Scaling of dc SMRT coefficient can be done in two ways. In the first method, the scaling is done so as to bring the mean of the image to the center of histogram range. In the second method, center of image histogram is shifted to the center of histogram range.

3.1.1 Modification of image mean

Average value or mean, μ of an image can be found from dc SMRT coefficient as

$$\mu = \frac{S(0,0)}{N^2} \quad (3)$$

When c_{dc} is changed regularly, regular changes in image mean is observed without any change in SD. The lower(r_l) and upper(r_h) values of the histogram also change in a linear manner. A plot of scaling factor versus mean, r_l and r_h values for *lena* image is shown in Fig.3.

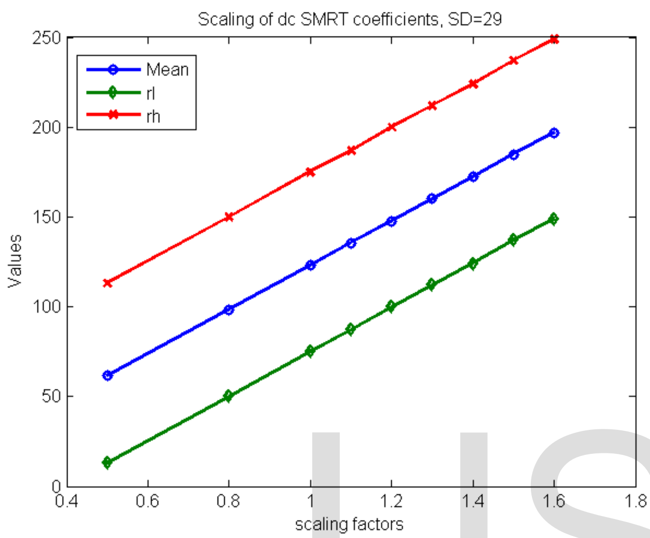

Fig.3. Plot of mean, r_l and r_h for changes in dc scaling factor

The scaling factor to bring the mean of the image histogram to $2^{(n-1)}$ can be found from

$$r_{shift} = 2^{(n-1)} - \mu = \frac{\tilde{S}(0,0) - S(0,0)}{N^2} \quad (4)$$

Thus,

$$c_{dc} = \frac{r_{shift} * N^2}{S(0,0)} + 1 \quad (5)$$

3.1.2. Shift of image histogram center

The Centre of image histogram, r_c can be found from r_l and r_h values of the image as given below

$$r_c = \frac{r_l + r_h}{2} \quad (6)$$

The shift in histogram to shift the image histogram center to $2^{(n-1)}$ is

$$r_{shift} = 2^{(n-1)} - r_c \quad (7)$$

and c_{dc} can be found from equation(5).

So by scaling $S(0,0)$ alone, the image mean and hence brightness can be varied without changing SD.

3.2 Contrast Variations using ac SMRT Coefficient

After fixing the image mean, histogram can be stretched suitably by scaling ac SMRT coefficients. Fig.4 shows a linear relationship between the scaling factor c_{ac} and the parameters SD, r_l and r_h. A scaling factor which stretches the histogram to its ends gives the maximum contrast. The shift in maximum pixel value, r_{hshift}, for 0.1 increase in scaling factor is calculated. The ac scaling factor is determined as

$$c_{ac} = \frac{2^n - (r_h + r_{shift})}{10 * r_{hshift}} + 1 \quad (8)$$

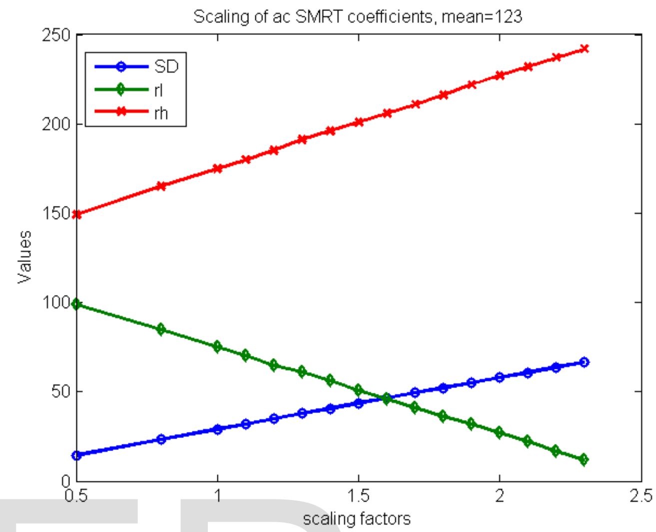

Fig.4. Plot of SD, r_l and r_h for changes in ac scaling factor

3 Extension to Color Images

Most of the electronic equipments acquire and display color images and hence enhancement of color images is also important. Classical approaches generally apply equalization of the red, green, and blue planes in the RGB images. However, this approach has an inherent problem of changing the hue of the output image. So image enhancement is performed in YCbCr color space and scaling is applied only to the luminance (Y) component keeping Cb and Cr constant. Finally the image is converted back to RGB space. This method produces better perceptible results as compared to scaling the R, G, and B planes separately.

4 Quantitative Evaluation of Enhanced Images

Assessment of images after enhancement is often difficult. Several measures are available in the literature. An enhancement measure using the concept of the second derivative is proposed by Panetta et. al. in [16], [17]. It is called Second Derivative like Measure of Enhancement (SDME) and is defined as

$$SDME = -\frac{1}{k_1 k_2} \sum_{m=1}^{k1} \sum_{l=1}^{k_2} 20 \ln \left| \frac{I_{max}^{l,m} - 2I_{cen}^{l,m} + I_{min}^{l,m}}{I_{max}^{l,m} + 2I_{cen}^{l,m} + I_{min}^{l,m}} \right| \quad (9)$$

where an image is divided into $k_1 \times k_2$ blocks

$I_{max}^{l,m}$, $I_{min}^{l,m}$ and $I_{cen}^{l,m}$ refers to the maximum, minimum and central pixel values in each block of the image. The block size

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should be an odd number. Higher the value of SDME, better is the enhancement.

6 Results and Discussion

Histogram Equalization (HE) is one of the most common methods used for image enhancement. It may increase the contrast of background noise, while decreasing the usable signal. This technique may produce images with over enhancement. It tends to introduce some annoying artifacts and unnatural enhancement.

In Fig.5, (a) shows a low contrast image, (c) its histogram equalized image and (e) enhanced image using the proposed method while (b), (d) & (f) show the respective histograms. Similarly, Fig.6 and Fig.7 show the enhancement for two other low contrast images. Analysis of the results shows that the proposed enhancement method works well for low contrast images. Generally for medical images, histogram stretches to both the ends and hence there is no scope for further enhancement by contrast stretching. But there may be certain objects of interest that is hidden as a low contrast sub image. In such cases, this method can be used to enhance the image locally.

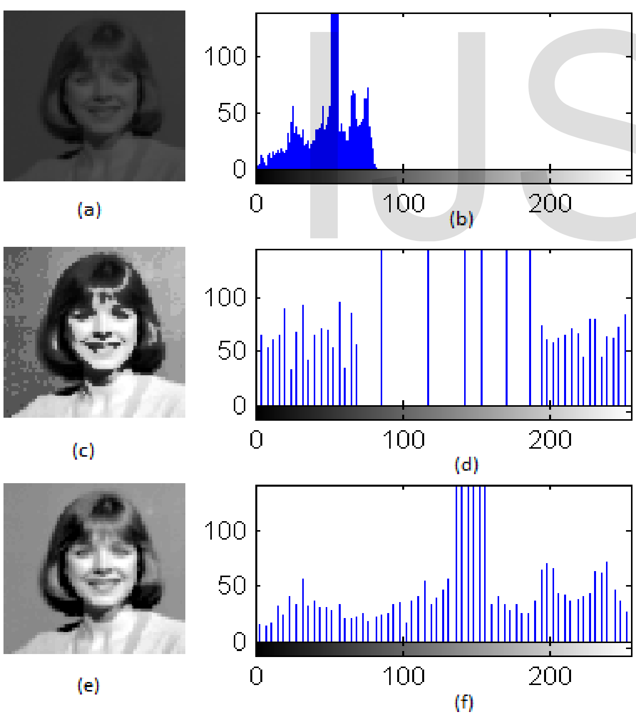

Fig.5. Images and their histograms (a)&(b) Original(*woman* image) (c)&(d) Enhanced using HE (e)&(f) Enhanced using proposed method(c_{dc}=2.66 and c_{ac}=4.15)

Sometimes mammograms are not well defined and detection of micro calcifications is important in the early detection of breast cancer. Computer aided analysis of mammograms depends on regions of interest (ROI) that are normally low in contrast. A contrast stretching and brightness improvement may bring the ROI better for analysis and easy diagnosis. A mammogram and a low contrast sub image are shown in Fig.8. Histogram equalized and the enhanced image using the proposed method is shown in Fig.9.

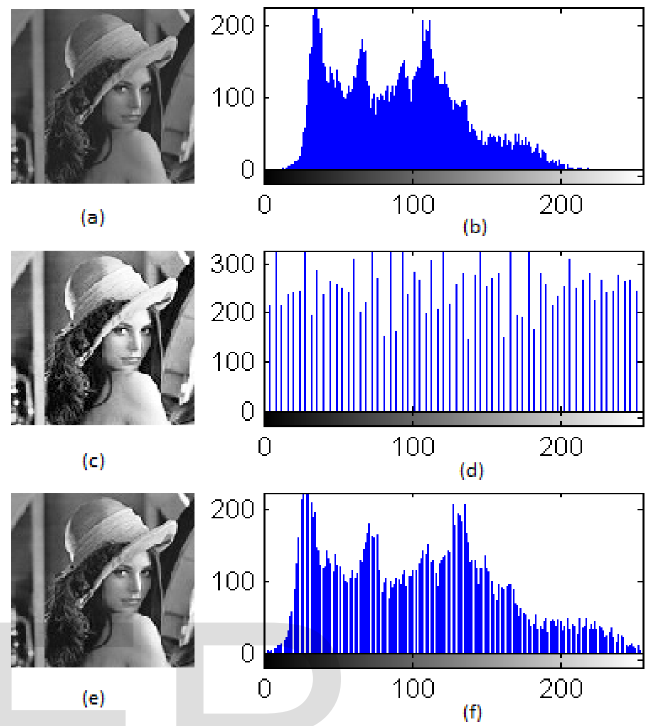

Fig.6. Images and their histograms (a)&(b) Original(*lena* image) (c)&(d) Enhanced using HE (e)&(f) Enhanced using proposed method(c_{dc}=1.16 and c_{ac}=1.38)

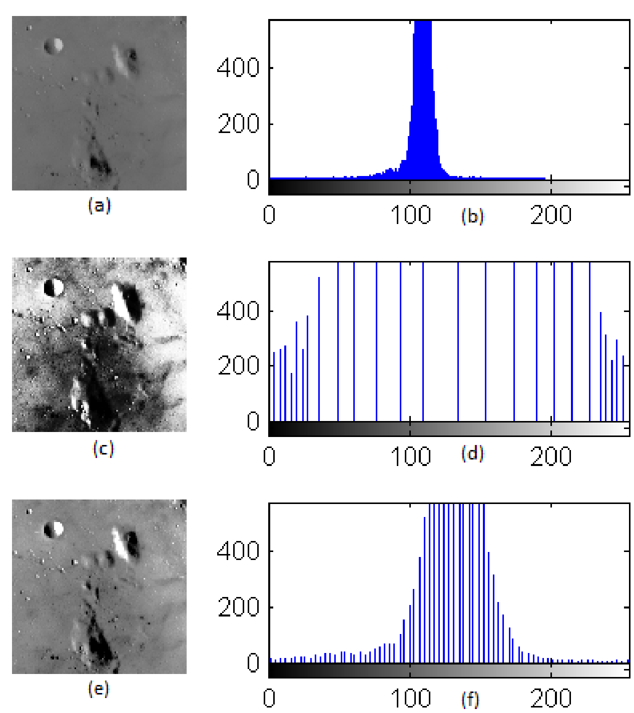

Fig.7. Images and their histograms (a)&(b) Original(*lena* image) (c)&(d) Enhanced using HE (e)&(f) Enhanced using proposed method(c_{dc}=1.18 and c_{ac}=2.01)

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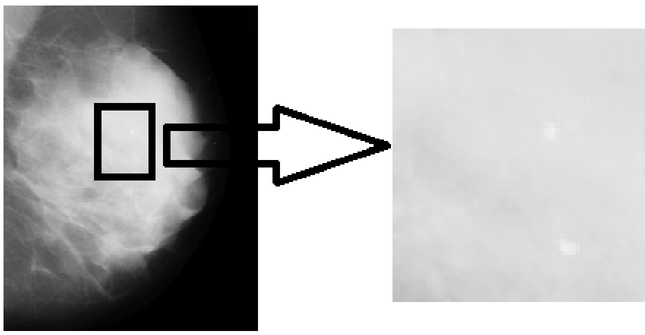

Fig.8. Mammogram image and low contrast subimage

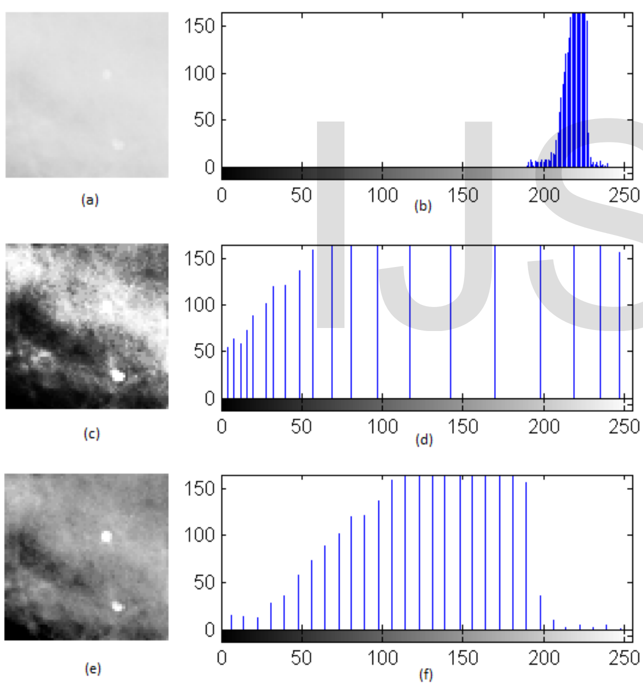

Fig.9. Mammogram images and their histograms (a)&(b) Original (c)&(d) Enhanced using HE (e)&(f) Enhanced using proposed method(c_{dc}=0.60 and c_{ac}=8.34)

The improvement of the brightness, contrast and visual quality of images can be verified using SDME measure and the values obtained for the images under consideration are shown in Table.1. It shows that the proposed method is superior to histogram equalization method.

Application of the above method to chrominance component of the YCbCr space and RGB components of the RGB space of color images are shown in Fig.10.

The enhanced images show that the proposed automatic contrast enhancement method gives better contrast and brightness for monochrome and color images and this method can give good performance for low contrast images.

TABLE 1
COMPARISON OF *SDME* OF VARIOUS IMAGES FOR HE AND PROPOSED METHOD

Images	SDME		
	Original Image	HE	Proposed
Lena	23.57	57.49	99.91
Woman	27.32	47.96	144.74
Moon	14.60	53.32	161.81
Mammogram	92.91	61.88	223.26

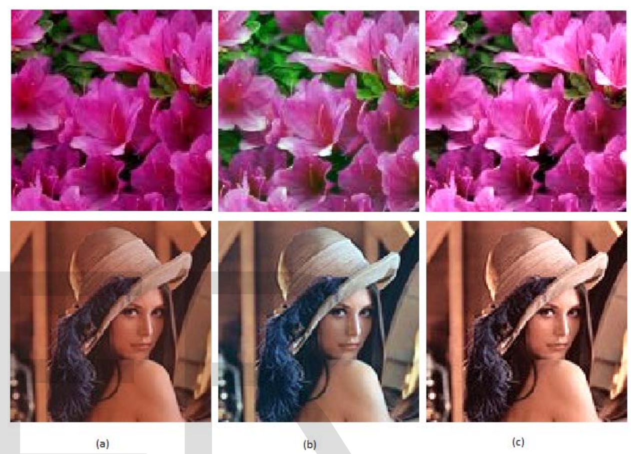

Fig.10. Application to color images (a) original image (b) using RGB space (c) using YC_bC_r

6 Conclusion

An important aspect of image processing is the flexibility in developing a linear, automatic, simple, yet powerful enhancement techniques based on statistical measures to have a close, predictable correspondence with image appearance. In this paper, a simple, automatic, brightness and contrast enhancement method that uses transform based contrast stretching is presented. By controlling dc SMRT coefficient, any low contrast image can be brightened or darkened. Dynamic range can be changed and thereby contrast can be improved by scaling ac SMRT coefficients. The performance of this method is compared with classical Histogram Equalization technique and quantitatively assessed using SDME. Experimental results show that the proposed method outperforms the HE quantitatively and qualitatively.

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