DENTAL X-RAY IMAGE ENHANCEMENT BASED ON HUMAN VISUAL SYSTEM AND LOCAL IMAGE STATISTICS.

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***Abstract**: An X-ray/Clincal medical image generally suffers from low contrast quality and degradations which vary from one region to another. Extraction of features in medical science and image processing is a matter of study and research. X-rays contain high redundancy, as far as background information is considered and in a way govern local image statistics. Contrast enhancement techniques based on visual perception criterion [1][2], deal in use of local (3x3) edge operators for computation of local image statistics of non-filtered images for contrast modification. In context to our earlier work and findings in [3], we suggest the use of LoG filter for contrast improvement process in place of methods discussed in [1][2]. An adaptive technique is suggested to improve the contrast quality of dental X-ray image using the Laplacian-of-a-Gaussian (LoG) Filter.*

Biologically, LoG Filter has a similar profile to the response of the receptive fields in the Human Visual System (HVS) [4]. Here, the results obtained reveal that LoG Filter is the best choice, whose standard deviation parameter sigma 's' can be conveniently used to tune the pixel value to a maximum gray value of 255.000000 and a minimum gray value of 0.000000 in our process of contrast modification. A description, an implementation, an estimate of the contrast gain and comparison of performance of various edge detectors is presented. Implementation of LoG Filter serves to be the best choice in the process of contrast modification and achieve high contrast gain.

1. INTRODUCTION

The raw data obtained directly from X-ray acquisition device may yield a relatively poor image quality representation. In case of medical images human intervention and perception is of prime importance. Interpretation of fine features in various contrast situations is a difficult task. HVS is sensitive to contours/edges in an image and to luminance contrast. Many researchers as referred in [1],[2],[3] have proposed different methods for contrast modifications and hence there is a need to investigate and develop a standard contrast modification approach suitable for different kind of images. Mostly, quality improvement techniques are qualitative, and adhoc, they can yield modified contrast acceptable to the psychovisual nature of individual observer or specific demand of an application. There is no unique theory for quality improvement of contrast in images. An Adaptive contrast enhancement and de-enhancement with noise reduction for improving contrast quality of Test Lena image using LoG Filter is carried out using local image statistics [3].

2. Processing Concept

In the case of medical images we consider the spatial domain for computation and determination of contrast transformation function using adaptive neighbourhood windowing. The process for quality improvement of contrast requires contrast enhancement or de-enhancement[3]. It is altogether a process of adapting an image to help our perceptual system for recognition of the image details in the X-ray Film. The work in [1], [2], [3] are based on theory of edge detection [5] and visual perception criteria [6]. Frank Neycenssac [7], has presented a linear method of contrast enhancement using LoG Filter. The major concern in the suggested scheme is choice of scale factor "σ" and high dependency on display factor "β" for high enhancement. Increasing β, image tends to binarization and resolution loss, as mentioned earlier. As with HVS, contrast modification technique must deal with the processing of gray levels about the contours/edges within the image. In this paper we present our results upon the choice, usage and implementation of edge detectors and contrast transformation function. The major concern is centered about choice of window size and size of feature to be experimented upon. The performance of the contrast improvement technique is also based upon the size of the object within the image so local image statistics govern the transformation process to a larger extent. The effective contextual region does govern the support extended by local image statistics required for contrast modification.

3. Choice of Edge detector and Edge detection Technique

The method [1][2] are centered about edge detection based upon the derivative approach. Now, the dimension of the neighbourhood, choice of edge detector and weights assigned to each pixel of the neighbourhood greatly influence the local image statistics and hence contrast. Table 3.1 (A) illustrates some basic local (3x3) edge templates. The major concern in usage of basic (3x3) edge detectors/masks is need for application of 8 different masks to determine all possible edges within an image as shown in Table 3.1 (B) for Sobel (2).

Table No. 3.1(A) Local (3x3) Edge detectionTemplates.

Prewitt(1)	Prewitt (2)	Sobel (1)
-1 -1 -1 0 0 0 1 1 1	1 0 -1 1 0 -1 1 0 -1	-1 -2 -1 0 0 0 1 2 1
Laplace(1)	**Laplace (2)**	**Faler Quick Mask.**
1 1 1 1 -8 1 1 1 1	0 1 0 1 -4 1 0 1 0	-1 0 -1 0 4 0 -1 0 -1

Table 3.1 (B) Eight different Local (3x3) Edge detection Templates of Sobel Filter.

1	**2**	**3 (used)**	**4**
1 2 1 0 0 0 -1 -2 -1	2 1 0 1 0 -1 0 -1 -2	1 0 -1 2 0 -2 1 0 -1	0 -1 -2 1 0 -1 2 1 0
5	**6**	**7**	**8**
-1 -2 -1 0 0 0 1 2 1	-1 -2 0 -1 0 1 0 1 2	-1 0 1 -2 0 2 -1 0 1	0 1 2 -1 0 1 -2 -1 0

This situation is well handled by Laplace and Faler Quick Mask, but again, tailoring suitably the nine entries for these templates is also a cumbersome job. The Laplacian mask evokes strong response to stray noise pixels. So, better utilization of the Laplacian is to precede it by convoluting the image by a digital mask having a Gaussian function distribution to smoothen the image profile. Then apply the Laplacian mask on the smoothed image. Finally, find the zero-crossings in the image. The edges are found by differentiating a profile and finding where the differentiated image changes sign, correspnding to a maximum (or minimum) of the original profile. So Laplacian of Gaussian (LoG) filter can be one of the suitable candidate for edge detection as against basic (3x3) edge templates of Laplace, Sobel. [1]

4. Contrast modification technique and related issues

The adaptive technique of contrast enhancment and de-enhancement, originally suggested by L. Dash and Prof. B. N. Chatterjee [2] is based upon the basic A. Beghdadi and Le Negrate's Method [1] for contrast enhancement. In their methods, there is a need for justification on the choice of basic (3x3) edge detectors used for contrast modifications. A. Beghdadi and Le Negrate [1] contrast enhancement scheme does not use it as an evaluation of the results, but to determine the gray level increase (or decrease) on either side of the contour position. Also the interpolative scheme [2] does not evaluate its results and is user interactive with a high degree of subjective approach. An adaptive technique for contrast enhancement and de-enhancement for Lena image is studied using the LoG Filter [3], results indicate better contrast modification as compared to [1][2]. Here LoG filter standard deviation parameter sigma 'σ' is adaptively/conveniently chosen to detect required edges and then tune the pixel value to a maximum gray value of 255.000000. Appropriate choice of standard deviation 'σ' helps in fine-tuning of final contrast value of the processed image.

In this paper we present a HVS based process by implementing (3x3) and (7x7) LoG Filters. The implementation is based upon the measure "k". Sampling of the LoG Filter introduces this parameter "k" which is dependent on the 'σ' amd the kernel size M = (2h+1) where "h" is the window size. Value of "k" must be closer to unity. Larger the value of 'σ' and 'M', the closer is the discrete filter to the ideal continuous one then 'k' comes close to unity [7]. We restrict the value of $k < 1.17363$, for (3x3) LoG Filter and in the case of (7x7) LoG Filter, $k < 1.02879$. Different values of 'σ' are used to indicate the effectiveness of contrast enhancement.

4.1. Beghdadi and Le Negrate's Method: -

As per Beghdadi and Le Negrate [1], the contrast associated with each pixel is defined with respect to its gray level position from mean gray level of object boundaries. Their method can be described as follows -

1. Choose an odd window size, centered on pixel (k, l)
2. Compute edge value a_{ij} of each pixel (i, j) using Laplacian / Sobel's operator.
3. For all pixels (i, j) of window W_{kl} compute the mean edge gray level $E_{k\,l}$.
4. Compute the local contrast C_{kl} associated to the current pixel (k, l) center of $W_{k,l}$.

5. Transform contrast C_{kl} into $C'_{kl} = F(C_{kl})$ using a function `F' satisfying the conditions.

$C_{kl} \in [0,1] : F(C_{kl}) \geq C_{kl}$ and $F(C_{kl}) \in [0,1]$ (4.1)

use the square root function. $C'_{kl} = (C_{kl})^{1/2}$. This is because as $0 \leq C_{kl} \leq 1$, it becomes $C'_{kl} \geq C_{kl}$ and also $0 \leq C'_{kl} \leq 1$. Various functions used for enhancing contrast to C'_{kl} are as proposed by A.P.Dhavan et al are -

(i) $F(C_{kl}) = \ln(1+n C_{kl})$ (ii) $F(C_{kl}) = \tanh(n C_{kl})$ (iii) $F(C_{kl}) = 1 - \exp(-n C_{kl})$. (4.2)

6. After contrast transformation, immediate step is to determine the Modified Gray Level.

$$X'_{kl} = \overline{E}_{kl} \frac{(1+C'_{kl})}{(1-C'_{kl})} \ldots\ldots\ldots\ldots X_{kl} > \overline{E}_{kl} \qquad X'_{kl} = \overline{E}_{kl} \frac{(1-C'_{kl})}{(1+C'_{kl})} \ldots\ldots\ldots\ldots X_{kl} \leq \overline{E}_{kl} \quad (4.3)$$

7. Repeat the treatment for each pixel.

4.2. Prof. B. N. Chatterjee and L. Dash Method : -

According to their suggested modification, an adaptive technique is proposed for image enhancement and de-enhancement using a single transformation function.

Their Suggested Modification in [1] is as–

The proposed modification for contrast transformation is for step 5 of the basic [1] algorithm. The contrast C_{kl} associated to pixel is to be transformed using function `τ' such that $C'_{kl} = \tau(C_{kl})$; where the function `τ' must satisfy the condition.

$\tau(C_{kl}) \geq C^{\alpha}_{kl} : C_{kl} \in [0,1] : \tau(C_{kl}) \in [0,1]$ where $\alpha \in [0,\infty]$ (4.4)

The method remains the same with only change in the power variable `α' introduced for the variable C_{kl}. Thus value of 'α' can be as-

$\alpha > 1$: Contrast de-enhancement. [greater α; higher de-enhancement]

$\alpha = 1$: No change in contrast.

$\alpha < 1$: Contrast enhancement. [smaller α; higher enhancement]

5. Dental X-ray image enhancement and use of LoG Filter

Medical X-ray images are normally dark images with low visibility as in case of MRI, bright spots in image while one deals with chromosomes or any such study of microscopic images, mid-range low contrast images are generally seen in case of CT-scan images. Also extraction of features in medical science and image processing is yet a matter of study and research. X-rays contain high redundancy as far as background information is considered. A x-ray film is a plane representing digital image data of two dimension structure, built in three dimension. Also the film is viewed to contain a number of regions within the object superimposed on the background level generally having low contrast. The major concern is centered about choice of window size and size of feature to be experimented upon.

The techniques [1][2], do not estimate the modified contrast values in context to the implementation and choice of a particular basic (3x3) edge operator. In our earlier work [3], the implementation of LoG Filter is dealt in extent and results show that it serves to be the best for contrast improvement of test image Lena. In this work an implementation of LoG filter for edge detection in Dental X-ray image (43x55) is studied in context to contrast modification.

We propose to replace classical edge detection by LoG Filter, in step 2 of [1][2]. In context to implementation of transformation function to deal with contrast stretching shall be based upon the contrast profile of the image. Here it is proposed to replace the fixed power transformation function [1][2] by **sinh(Alpha_e*C_{xy})** function as in our earlier work [3], by converting original image into a mid-range intensity image. The results indicate a better edge detection and contrast stretching as compared to the scheme suggested in [1], [2]. Also our scheme permits tuning of gray levels at two levels, first is the standard deviation and other is the contrast enhancement / de-enhancement factor, a plus point in execution of our algorithm over [1][2].

6. Experiments and Results

The interpolative technique of adaptive contrast enhancement and de-enhancement [2], is based upon the basic locally adaptive method of A. Beghdadi and Le-Negrate's Method [1] which uses fixed power transformation function for contrast enhancement. Franck [7] work is a linear technique of contrast enhancement using Log Filter but highly dependent on display factor "β". Here in our work we have consider enhancement of the original contrast of Dental X-ray image. Caries formation in the tooth is seen more clearly and distinctly after processing. The outline / border of the tooth visibility is also studied based on various edge detectors. As the tooth is main object of concern, we have chosen W_size=(43x43) for processing. The contrast amplification of the X-ray image and related parameters are determined. The image parameters such as window size (W_size), standard deviation sigma 'σ' of

Gaussian function and Alpha_E for different transformation functions are suitably chosen to achieve maximum final contrast F_Contrast, maximum final gray value F_Max=255.000000, for a pleasant appearance of image . Noise in dental image, is reduced by increasing the value of 'σ' the standard deviation of the Gaussian smoothing function. Inherently in the method, in step 3, it involves the mean edge gray value so noise is taken care of during computation of local contrast. Contrast De-enhancement process can be implemented for noise reduction. Great attention is paid to maintaining the contrast profile in the image. Here, the Contrast gain and final contrast of the image, is used as a figure of merit for analysis of image.
We define final contrast as –

$$F\_Contrast = \frac{F\_Max - F\_Min}{F\_Max + F\_Min} \tag{6.1}$$

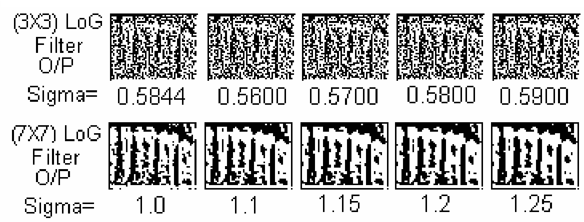
and the global contrast gain in the image is –

$$Contrast \quad Gain = \frac{F\_Contrast}{O\_Contrast} \tag{6.2}$$

6.1 Edge detection of Dental X-ray Image :-

The basic (3x3) edge templates Laplace and Sobel edge operators [1], [2] etc., results are not satisfactory in their usage for determining the local edges. Both Laplace and Faler Quick Mask mask yield over-enhanced edges. There is a high degree of dis-similarity in the detected edges as seen in Fig 1. (a). The local image statistics computation for contrast modification is wholly centered about detection of edges within an image. So, choice of edge detector, is an important criteria while considering visual perception criterion for contrast modifications.[3]

[**Fig.1(a)**Original Dental X-ray image & Edge detected outputs of basic (3x3) edge operators]



[**Fig 1. (b)** Edge detection using (3x3) and (7x7) LoG Filter.]

Table 6.1(A). Results of contrast enhancement using basic (3x3) edge templates.

Filter type	Laplace (1)	Sobel (1)	Prewitt(1)	Faler Quick Mask	Laplace (2)	Sobel (2)	Prewitt(2)
Variables	1 1 1 1 -8 1 1 1 1	-1 -2 -1 0 0 0 1 2 1	**-1 -1 -1 0 0 0 1 1 1**	-1 0 -1 0 - 4 0 -1 0 -1	0 1 0 1 - 4 1 0 1 0	-1 0 1 -2 0 2 -1 0 1	1 0 -1 1 0 -1 1 0 -1
Alpha_E	**0.3316361**	**0.3320286**	**0.3305909**	**0.3444242**	**0.33208835**	**0.3359824**	**0.3357041**
F_Max	255.000015	255.000031	**255.000000**	255.000031	255.000000	255.000015	255.000031
F_Min	6.093649	6.101451	**6.072912**	6.353772	33.972778	6.180605	6.174998
F_Contrast	0.953322	0.953264	**0.953477**	0.951378	0.953255	0.952672	0.952714

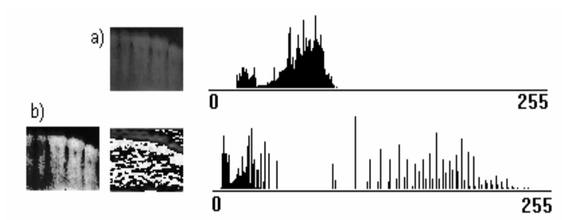
Table 6.1(B). Results of contrast enhancement using (7x7) LoG Filter.

Filter size	**(7x7) KERNEL SIZE**			
Sigma	1.0	**1.1**	1.15	1.2
"k"	1.00410	**1.01256**	1.01958	1.02878
Alpha_E	0.3254069	**0.3238012**	0.3240159	0.3246172
F_Max	255.000031	**255.000031**	255.000015	255.000015
F_Min	5.970906	**5.939562**	5.943748	5.955476
F_Contrast	0.954241	**0.954476**	0.954444	0.954356

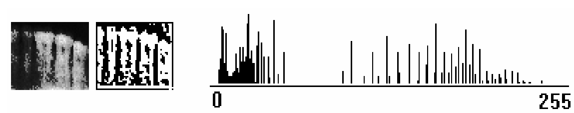
[**Table 6.1.** Results of implementation of Fixed Power Transformation Funtion using basic (3x3) edge templates and (7x7) LoG Filter for edge detection.]

6.2 Contrast Enhancement of Dental X-ray image:-

Image enhancement of clinical images, X_rays, etc., has proved to be one of the major advantage in image processing. It is however felt that processing must involve or be based upon HVS. Understanding clinical images, X-rays etc., needs the intervention of the physicians for the final judgements and decision-making. Here in this work, an implementation of contrast enhancement [3] to medical images, a dental X_ray is considered. The original image has poor visibility and the caries formation is not much clear as seen in Fig 1(a). Using the adaptive technique of selective image contrast enhancement the enhancement of individual tooth can be achieved [3]. The best results of Contrast Enhancement using Fixed Power Transformation, and corresponding values of enhancement factor Alpha_E, are as given in Table 6.1 (A) Table 6.1 (B). Here in Table 6.1 (A) the Prewitt (1) mask yields the maximum contrast followed by the others. Faler Quick Mask yields the lowest. In Table 6.1 (B) it is seen that maximum gray value can be tuned to 255.000000 by varying "σ" for given processing conditions of W_size = (43x43); Enhancement Factor Alpha_E = 0.3238012 . Original Dental X-ray image details are O_Max = 101.000000; O_Min = 18.000000; O_Contrast = 0.697479. Fig 2.1 (A) & Fig 2.1(B) illustrates the result of basic (3x3) edge template and (7x7) LoG filter. The edge map using (7x7) LoG Filter is far better as compared to that of Prewitt Filter.



[**Fig 2.1 (A)** Original image (a) and enhancement of Dental X-ray Image (b) along Histograms and its edge detected output using Prewitt (1),W_size = (43x43), Alpha_E = 0.3305909 & Fixed Power Transformation]

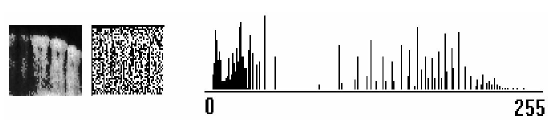


[**Fig 2.1 (B)** Contrast Enhancement of Dental X-ray Image using (7x7) LoG Filter along with along with its edge detected output and Histogram. W_size = (43x43), Alpha_E = 0.3238012, and σ = 1.1, k=1.01256 & Fixed Power Transformation]

Fig 2.2 illustrates the results of implementing (3x3) LoG filters. Using, σ = 0.5 the corresponding (3x3) LoG kernel yields higher contrast enhancement as compared to basic (3x3) Prewitt (1) edge detector, as in Table 6.1(A). In a way there is high possibility to achieve results better than basic (3x3) edge detectors by tuning a single parameter viz., the standard deviation "σ" of the LoG Filter. Here too, the edge map using (3x3) LoG Filter is better than those of basic (3x3) edge detectors as seen in Fig 2.2

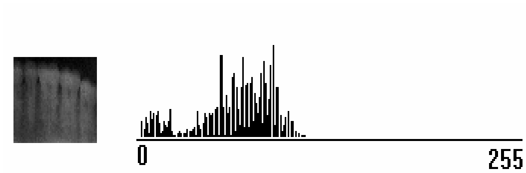
[**Table 6.2** Enhancement results using (3x3) LoG Filter.]

Filter size	**(3x3) KERNEL SIZE**			
Sigma	**0.5**	0.55	0.57	0.5844
"k"	**1.17363**	1.09234	1.08186	1.07978
Alpha_E	**0.323963**	0.32745895	0.32808495	0.32830635
F_Max	**255.000000**	255.000015	255.000000	255.000015
F_Min	**5.942716**	6.011126	6.023436	6.027793
F_Contrast	**0.954452**	0.953940	0.953848	0.953815



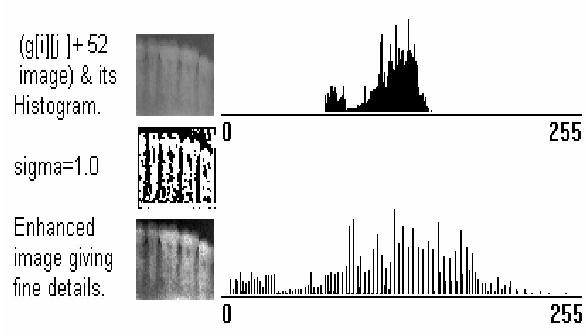
[**Fig 2.2** Contrast enhancement using (3x3) LoG Filter to achieve maximum gray value of F_ Max =255.000000, W_size (43x43), Alpha_E = 0.323963 and σ = 0.5, k=1.17363 & Fixed Power Transformation.]

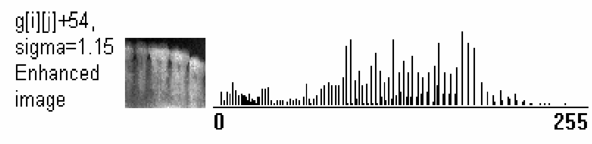
In all above experiments it was found that the lower range of histogram of the image is not well transformed after enhancement and also that the transformed image histogram does not appear to be an amplified version of the input image. So choice of transformation function is important. Here we propose use of sinh (Alpha_E*C_{xy}) function which utilizes both the upper and lower bounds the input image, yields a maximum stretch in the contrast and maintains the histogram profile. Fig 3 (A) illustrates the contrast stretch of original Dental X-ray image, wherein the minimum gray level achieved after transformation is exactly 0.000000 using sinh(Alpha_E*C_{xy}) function.



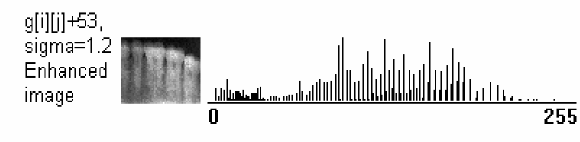
[**Fig 3 (A)** Contrast enhancement using (7x7) LoG Filter, minimum gray value F_Min=0.000000, maximum gray value of F_ Max = 119.897995, F_Contrast=1.000000. W_size (43x43), Alpha_E = 1.4706375 and σ = 1.0, k=1.00410 & sinh ( ) Transformation Function along with Histogram]

Quantitatively, in Fig. 3 (A) final contrast value is 1.000000, however qualitatively one is exactly not satisfied with the intensity of the modified image. As the Dental X-ray image has low contrast and low visibility, we increase the intensity by shifting the gray level such that the mid value of the histogram is around 110.000000 to 115.000000. Fig 3 (B), (C), (D) & Fig 4. illustrates the contrast stretch of original Dental X-ray image, wherein the maximum gray level achieved after enhancement is exactly 255.000000 using sinh (Alpha_E*C_{xy}) function.



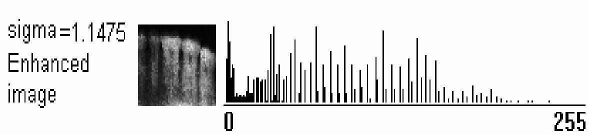


[Fig 3.(C)]



[Fig 3.(B)] **[Fig 3.(D)]**

[**Fig. 3 . (B), (C), (D)** illustrating implementation on gray level shifted Dental X-ray image to yield maximum gray value of 255.000000 using sinh ( ) function.]



[**Fig. 4.** Contrast enhancement using exponential function, {1 – [exp(-alpha_E*C_{XY})]}, (7x7) LoG, using σ =1.1475]

Table 6.3 Contrast Gain in enhanced Dental X-ray image for maximum gray value=255.000000.

Fig. No.	Transformation Function	Edge detector	Contrast Gain
2.1 (A)	Fixed Power [1][2]	Prewitt(1)	1.367033
2.1 (B)		(7x7)LoG	1.368465
2.2		(3x3)LoG	1.368431
3(A)	**Sinh( ) [3]**	(7x7)LoG , σ = 1.0	**2.108504**
3(B)		(7x7)LoG , σ = 1.0	**2.671090**
3(C)		(7x7)LoG, σ = 1.15	**2.681246**
3(D)		(7x7)LoG , σ = 1.2	**2.680263**
4	Exponential [1][2]	(7x7)LoG , σ = 1.1	1.412594

Numerous transformation functions are suggested till date. Implementation of any transformation function requires best utility of the display device and to see that the transformed image histogram is an amplified version of the original input image. Fig 3. illustrates an example where the original contrast O_contrast = 0.372197 and F_contrast =0.994172; which means an gain of 2.671090847. Table 6.3 shows how sinh(Alpha_E*C_{xy}), yields the highest contrast gain in its implementation in comparison to Fixed Power Transformation and Exponential function, the image brightness profile too is maintained. Our method yields uniform extension of the input image histogram & high contrast gain, improves quality and visibility of the X-ray image.

Conclusion:

Using sinh (Alpha_E*C_{xy}) function improves contrast better as compared to those in [1],[2]. Also, LoG Filter suits to be one of the best tunable/controllable edge detector in context to adaptive contrast modification as compared to basic (3x3) edge detectors. Our approach can serve to yield better contrast enhancement of medical images.

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