EFFECTIVE PROCESSING AND ANALYSIS OF RADIOTHERAPY IMAGES

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ABSTRACT

a-Si Electronic Portal Imaging Device (EPID) is an important tool to verify the location of the radiation therapy beam with respect to the patient anatomy. But, Electronic Portal Images (EPI) suffer from low contrast. In order to have better in-treatment images to extract relevant features of the anatomy, image processing tools need to be integrated in the Radiology systems. The goal of this research work is to inspect several image processing techniques for contrast enhancement of electronic portal images and gauge parameters like mean, variance, standard deviation, MSE, RMSE, entropy, PSNR, AMBE, normalised cross correlation, average difference, structural content (SC), maximum difference and normalised absolute error (NAE) to study their visual quality improvement. In addition, by adding salt and pepper noise, Gaussian noise and motion blur, we calculate error measurement parameters like Universal Image Quality (UIQ) index, Enhancement Measurement Error (EME), Pearson Correlation Coefficient, SNR and Mean Absolute error (MAE). The improved results point out that image processing tools need to be incorporated into radiology for accurate delivery of dose.

KEYWORDS

Amorphous Silicon (a-Si) detector, electronic portal imaging, image enhancement, image processing.

1. INTRODUCTION

For accurate delivery of radiotherapy it is mandatory to maximize the dose delivered to well defined targeted tumour volume and minimize the exposure to healthy surrounding tissues. [4] The use and development of active matrix flat panel amorphous silicon (a-Si) electronic portal imaging devices (EPIDs) for verification of Radiation Therapy (IMRT) is increasing. Electronic Portal Image (EPI) quality is poor due to Compton effect. [5] To produce higher quality EPI for assessment and to increase the treatment throughput, we tested an aggregation of image processing techniques to refine their visual aspect. [15] The operations were performed on 5 images of different organs under treatment - pelvis, chest, head, neck, thorax. Extending the work done in [15], this paper gives a qualitative and quantitative analysis of the effect of various operations on EPI thus proving the need of integration of image processing tools in radiation therapy process for error free delivery of treatment.

2. LITERATURE SURVEY

In the past decade, quite a less amount of work has been done on improving electronic portal image quality. Experiments were conducted to increase the contrast of portal images based on local enhancement to pixel values of image matrix and found that the processed images were superior in quality, however it was time consuming. [8] The influence of contrast enhancement,

DOI : 10.5121/sipij.2015.6203

noise reduction and edge sharpening was examined in 3-step sequence for 12 combinations of operations and results were compared for portal images obtained from PIPS-PRO system. Majority of the images had superior quality after processing but it was not enough to locate essential structures in all cases. [9] The use of Gray Level Grouping for global contrast enhancement and Adaptive Image Contrast Enhancement (AICE) for local contrast enhancement was suggested to enhance visual quality and contrast of the whole EPI. They concluded that these methods greatly improve perception quality of the images. [10] A qualitative analysis was shared by the authors where a plethora of methods were used on EPI and it was shown that the proposed hybrid method [15] performed better in terms of PSNR and RMSE.

3. IMAGE PROCESSING OF RADIOTHERAPY IMAGES

Steps for image processing of radiotherapy images as discussed in [15] are shown in Figure 1.

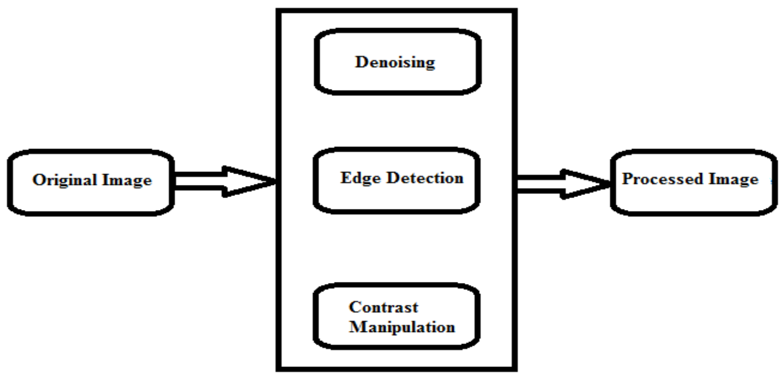

Figure 1. Image Processing of Radiotherapy Images

3.1. Denoising

Gaussian noise is obtained due to random fluctuations. During transmission, the capturing device has salt pepper noise. During radiotherapy, the size and shape of the tumour can change due to breathing or motion of organ/patient causing motion blur. [4] Therefore, by adding salt and pepper noise, Gaussian noise and motion blur to EPI, we calculate error measurement parameters like PSNR, MSE, RMSE, UIQ index, Enhancement Measurement Error (EME), Pearson Correlation Coefficient, SNR and Mean Absolute error (MAE). [12]

3.2. Contrast Manipulation

Contrast enhancement does not increase the inherent information content in the data but refines the image to make it better in quality than the original image. [6], [14] Mathematically,

$$I'(x; y) = f(I(x; y)) \tag{1}$$

where the original image is I(x,y), the output image is I'(x,y) after contrast enhancement, and f is the transformation function.

We have explored numerous contrast enhancement algorithms and filters in [15]. A potpourri of image analysis methods used in [15] are described below in short.

3.2.1. Gamma Correction or Power Law Transformation

Gamma is a non-linear form of increase in brightness. For low contrast images, $\gamma < 1$ improves the contrast of the image and $\gamma > 1$ reverses the effect and makes the image dark. We inspect results for $\gamma = 0.5$ and $\gamma = 2$. Results shown indicate that $\gamma < 1$ produces better EPI. Mathematically,

$$s = c\,\gamma \qquad (2)$$

where c and γ are positive constants. The resultant images are presented in [15].

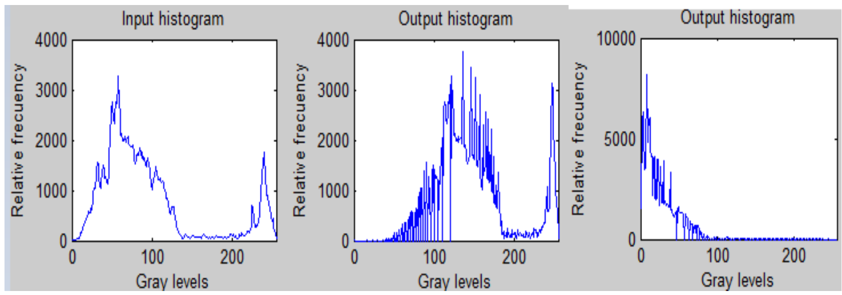

Figure 2. Histogram representation of Gamma Correction - Pelvis

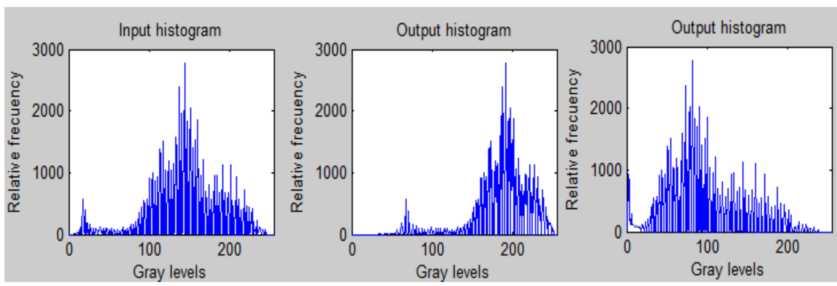

Figure 3. Histogram representation of Gamma Correction - Chest

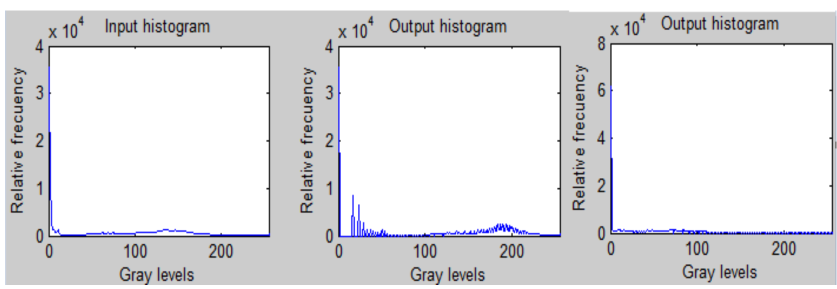

Figure 4. Histogram representation of Gamma Correction - Head

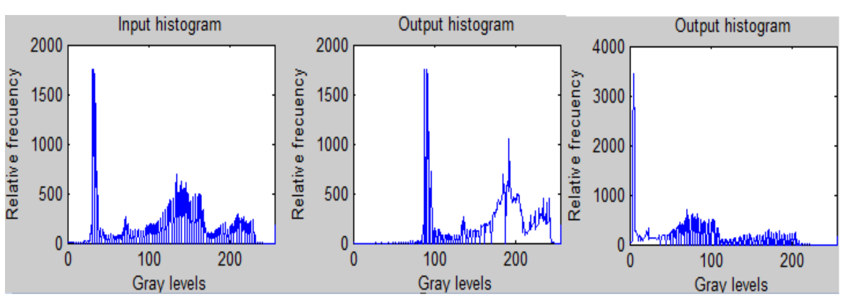

Figure 5. Histogram representation of Gamma Correction - Neck

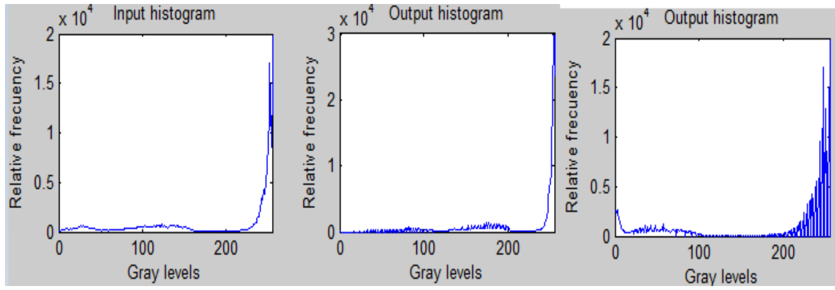

Figure 6. Histogram representation of Gamma Correction - Thorax

3.2.2. Logarithmic Transformation

It maps narrow range of low gray level values in the input image to a wider range of output levels and vice-versa by replacing each value by its logarithm; hence low intensity pixel values are enhanced. Mathematically,

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

where s is the output image, γ is the input image and c is a constant. The output histogram is more wide and has more gray levels than histogram of the original image as shown in Figure 7.

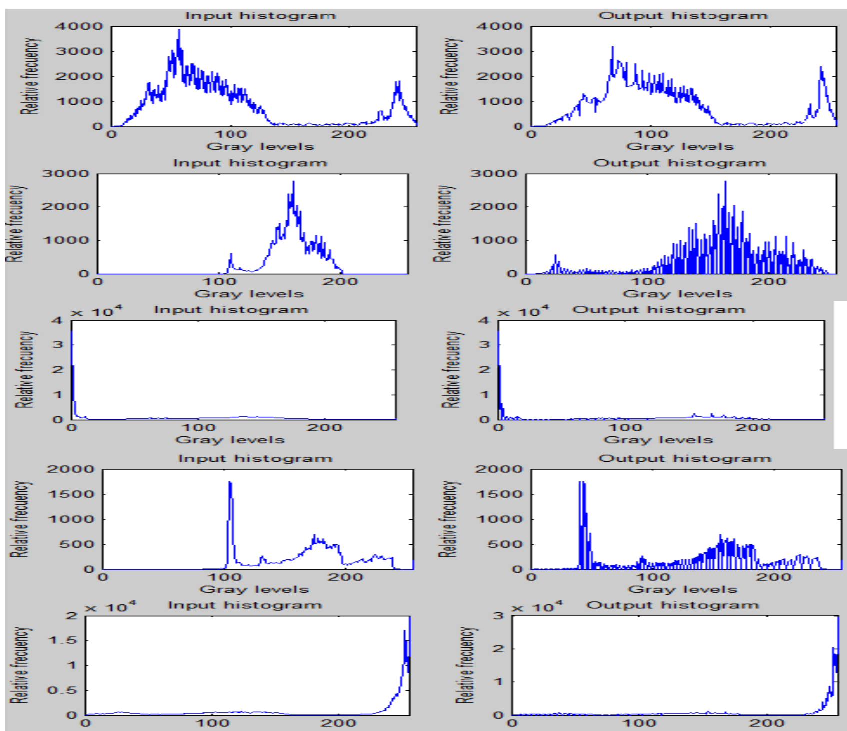

Figure 7. Histogram representation of Logarithmic Transformation - a) Pelvis, b) Chest, c) Head, d) Neck, e) Thorax

3.2.3. Histogram Equalisation

Histogram equalisation is one of the most common contrast enhancement filter that distributes the occurrence of pixel intensities evenly so that entire range of intensities is used efficiently. When gray levels are spread over in whole range i.e. (0, 255) then it is a well contrasted or equalised image. [2]

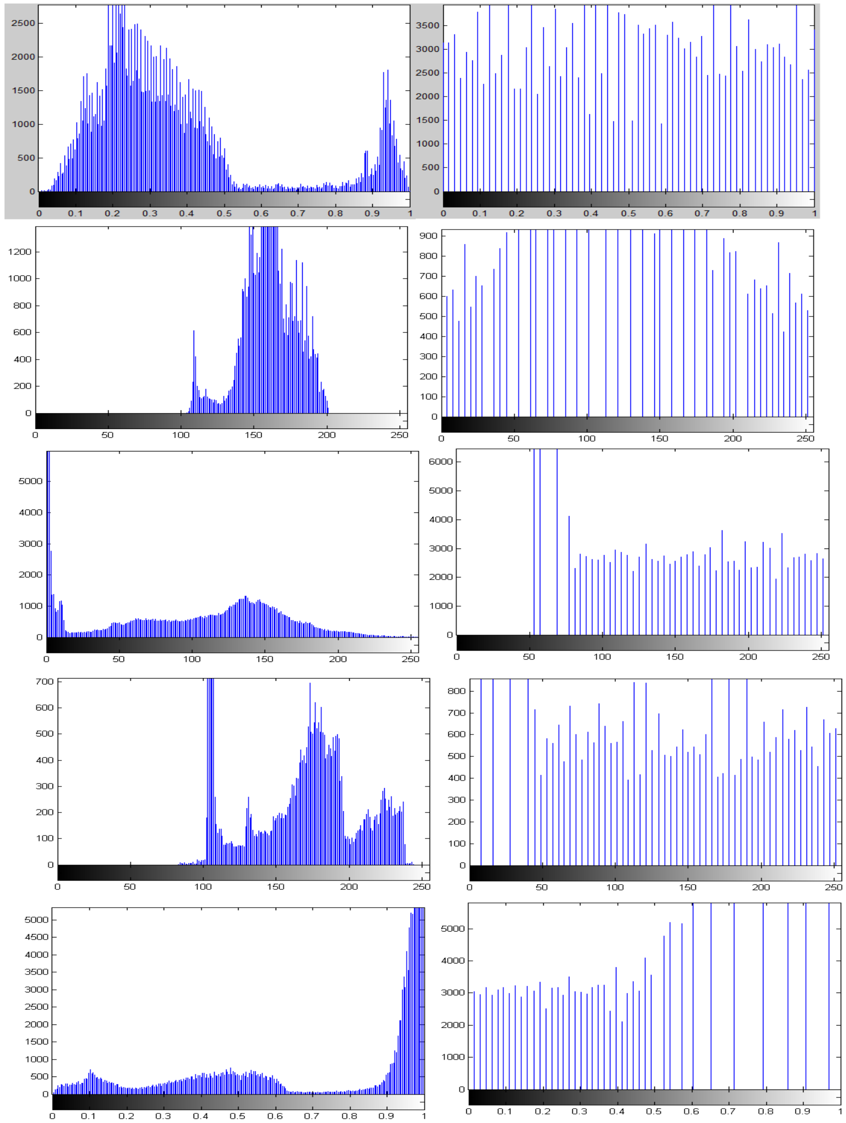

Figure 8. Histogram Equalisation - a) Pelvis, b) Chest, c) Head, d) Neck, e) Thorax

3.2.4. Contrast Limited Adaptive Histogram Equalisation (CLAHE)

In this algorithm, an image is divided into tiles and contrast of each tile is enhanced by clipping the histogram to avoid over-amplification of noise. Probability Distribution Function (PDF) is calculated for all bins and each one is checked. If the PDF is above the clip level, extra amount is accumulated and later redistributed. Later, all PDF values are modified and added to Cumulative Distribution Function (CDF). All the tiles are combined using bi-linear interpolation. [11] Clip level can vary from 0 to 1. However, a low clip limit value like 0.02 makes the accumulated sum significant, which when redistributed makes average height of histogram large. The parameters of CLAHE are size of the tile and clip level of histogram. The comparative sample results of the original, CLAHE and histogram equalised images for neck and pelvis are shown in Figure 9 and 10. [15], [16]

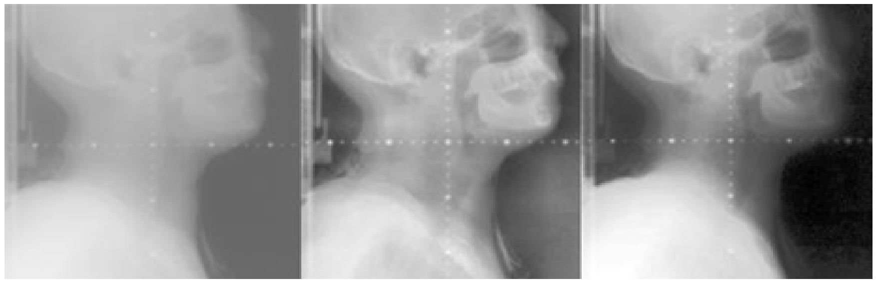

Figure 9. Neck: (a) original image, (b) CLAHE image, (c) Histogram equalised image

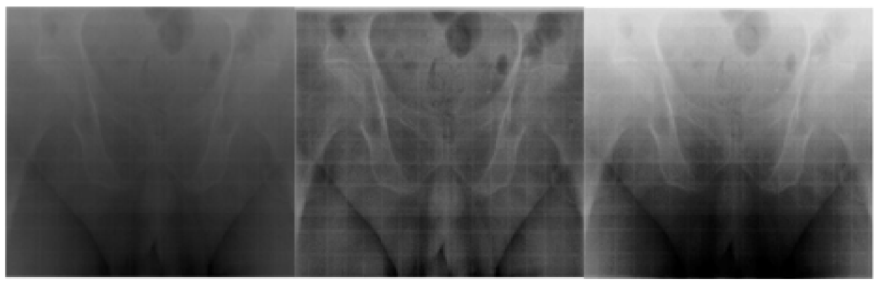

Figure 10. Pelvis: (a) original image, (b) CLAHE image, (c) Histogram equalised image

3.2.5. Image Negation

The negative of an image with grey levels in the range [0, L-1] is obtained by the negative transformation given by the expression,

$$s = L - 1 - r \qquad (4)$$

In the output image, dark areas become lighter and light areas become darker. [12]

3.2.6. Solarisation

This operation reverses the image tone and helps in contrast enhancement. It takes complements of all the pixels in the image whose gray-scale values are less than 128. [3]

3.2.7. Motion Blur Reconstruction using Weiner Filter

During radiotherapy, the size and shape of the tumour can change due to breathing or motion of organ/patient, this can cause motion blur. [4] Weiner filter applied in frequency domain de-blurs the image and helps to restore it as shown in Figure 11, 12 and 13. [17]

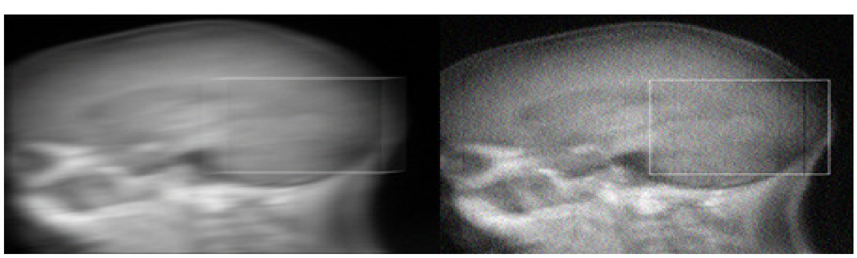

Figure 11. Head: Motion Blur and Reconstruction

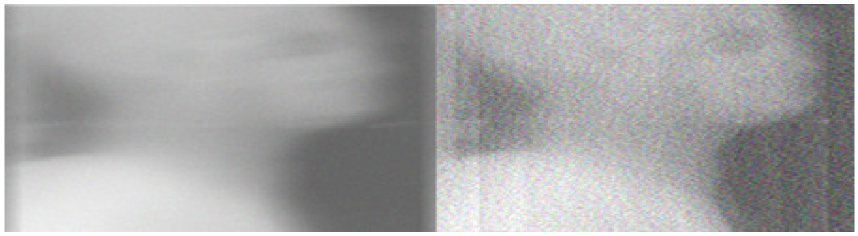

Figure 12. Neck: Motion Blur and Reconstruction

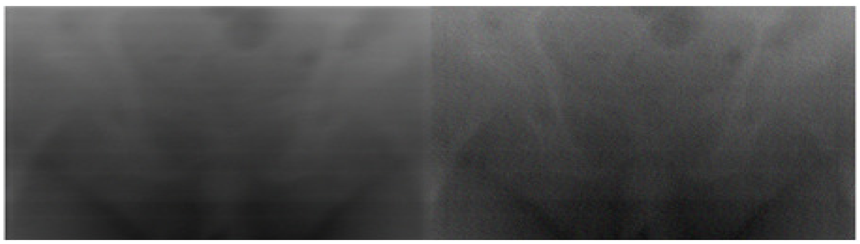

Figure 13. Pelvis: Motion Blur and Reconstruction

3.2.8. Proposed Method

Steps of the hybrid method proposed in [15]:

- Radiotherapy image acquisition in DICOM format,
- Normalise it in the range 0 to 1,
- Apply CLAHE algorithm,
- The resultant image is non-linearly median filtered and sharpened.

The sample results of negation, solarisation and the proposed method [15] are compared. The proposed method [15] produced better quality images and enhances the edges of the bones making soft tissue structures identification easier.

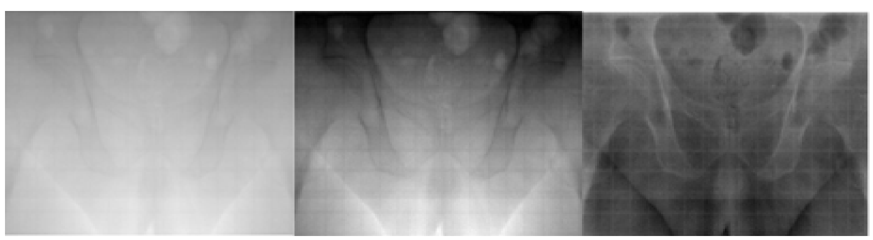

Figure 14. Pelvis: (a) Negation, (b) Solarisation, (c) Proposed Method

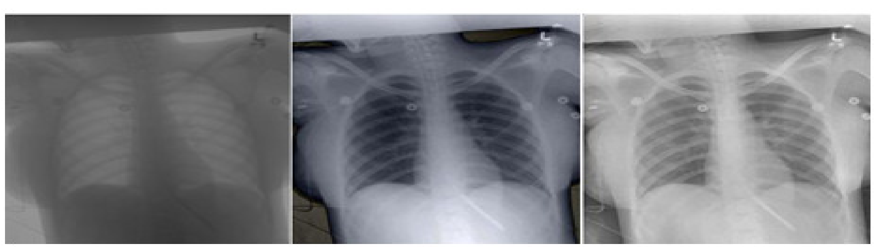

Figure 15. Chest: (a) Negation, (b) Solarisation, (c) Proposed Method

4. STATISTICAL PARAMETERS FOR COMPARISON OF IMAGE QUALITY

In this paper, we have explored numerous contrast enhancement algorithms and filters. Numerical quantities are required to quantify error, image quality and characterise the perceived brightness and contrast. The metrics used to inspect visual quality of image are described below.

4.1. Mean

Mean is a basic statistical measure for the overall brightness of a grey scale image. [1] It is seen that CLAHE and log transformation increase the brightness of the EPI as shown in Table 1.

Table 1. Mean for various techniques

Methods	Pelvis	Chest	Head	Neck	Thorax
Original Image	94.457	161.21	78.25	164.77	218.69
Histogram Equalisation	110.91	128.72	182.79	206.92	175.97
CLAHE	160	223.62	212.79	217.85	230
Negation	210.95	183.89	208.54	192.97	106.35
Solarisation	190.87	162.54	196.75	174.97	234.93
Log Transformation	184.52	238.02	176.36	227.55	240.81
Proposed Method	85.764	159.84	85.09	155.53	218.49

4.2. Standard Deviation

This parameter shows how much variation or "dispersion" exists from the average or expected pixel value. [1] A low standard deviation means that the data points tend to be very close to the mean and a high standard deviation means that the data points are distributed more discretely.

Table 2. Standard Deviation for various techniques

Methods	Pelvis	Chest	Head	Neck	Thorax
Original Image	61.22	18.25	68.5	40.97	67.4
Histogram Equalisation	65.44	74.72	78.91	77.05	85.39
CLAHE	85.96	51.73	99.64	55.56	52.92
Negation	42.33	80.52	65.29	83.69	116.19
Solarisation	30.99	15.54	48.19	28.53	36.32
Log Transformation	73.73	37.59	101.6	57.63	44.1
Proposed Method	25.49	31.8	70.72	45.69	60.81

4.3. Variance

It is a measure of contrast in neighbourhood and it summarizes the histogram spread. [1] Higher the variance, more is the dissimilarity and spread from the mean as shown in Table 3.

Table 3. Variance for various techniques

Methods	Pelvis	Chest	Head	Neck	Thorax
Original Image	3748.6	333.28	4692.6	1678.5	4542.8
Histogram Equalisation	4282.6	5582.6	6226.6	5937	7291.2
CLAHE	7389.3	1898	9928.7	3087	2801
Negation	1791.5	6483.6	4263.1	7004.8	13501
Solarisation	960.7	241.67	2322.2	814.12	1319.5
Log Transformation	5437.1	1413.3	1033.4	3321.6	1945.1
Proposed Method	647.44	1011.3	5002	2087.9	3698.2

4.4. Mean Square Error

For two monochrome images X and Y, one of the images is actual, one is desired. [12] Mathematically,

$$\mathrm{MSE} = \frac{\sum_{j=1}^{N}\left(\sum_{i=1}^{M}(X_{i,j} - Y_{i,j})^2\right)}{\mathrm{MN}} \qquad (5)$$

where M and N are the number of rows and columns in the input images and the sum over i, j denotes the sum over all pixels in the images. MSE quantities the average of squares of the errors between an actual and the desired image. This measure has a minimum when both images are almost similar. In measuring the degree of image enhancement, the higher the value of MSE, the better. Histogram equalisation produces better enhanced images and the proposed method catches up well with it.

Table 4. MSE for various techniques

Methods	Pelvis	Chest	Head	Neck	Thorax
Histogram Equalisation	2445.1	4310.6	3075	2569	9687
CLAHE	822.25	1298.6	772.7	556.5	211.7
Sharpening (default)	17.71	1.188	12.458	4.918	12.381
Negation	17.71	5592	28148	12207	51416
Solarisation	1164.7	3.61	2190.2	38.06	220.38
Proposed Method	1089.4	1327.3	809.89	588.9	232.6

4.5. Root Mean Square Error

RMSE is the root mean square error. It is given by:

$$\mathrm{RMSE} = \sqrt{\mathrm{MSE}} \qquad (6)$$

Table 5. RMSE for various techniques

Methods	Pelvis	Chest	Head	Neck	Thorax
Histogram Equalisation	49.45	65.55	55.45	50.69	98.42
CLAHE	28.67	36.03	27.79	23.59	14.55
Sharpening (default)	4.21	1.09	3.529	2.21	3.52
Negation	4.21	74.78	167.77	110.5	226.7
Solarisation	34.12	1.9	46.79	6.16	14.84
Proposed Method	33.01	36.43	28.45	24.26	15.25

4.6. Absolute Mean Brightness Error

AMBE is a luminance evaluation metric given by the absolute difference of input and output mean. It evaluates brightness preservation in the processed image. When AMBE is low, brightness preservation is better and the average intensity of the input and the output images is similar. [12] Mathematically,

$$\mathrm{AMBE}(X,Y) = |X_m - Y_m| \qquad (7)$$

where, X_m is the mean of input image, X = x (i,j) and Y_m is the mean of output image, Y = y (i,j).

Table 6. AMBE for various techniques

Methods	Pelvis	Chest	Head	Neck	Thorax
Histogram Equalisation	18.45	32.49	104.3	42.15	42.73
CLAHE	67.54	51.57	76.17	53.09	11.3
Negation	118.5	22.68	130.3	28.2	112.3
Solarisation	98.41	1.33	118.5	10.2	16.23
Log Transformation	92.07	76.8	98.1	62.8	22.11
Proposed Method	6.69	1.37	6.83	9.24	0.21

4.7. PSNR

It is a measure of de-noising and contrast enhancement. It is expressed in dB. More the PSNR, better is the image quality. When the value of PSNR is or exceeds 40 dB, the two images are indistinguishable. If the pixels are represented using 8 bits per sample, then 255 is the maximum possible value that can be attained by the image. [12] Mathematically,

$$\mathrm{PSNR} = 10 \log \frac{255^2}{\mathrm{MSE}} \tag{8}$$

Table 7. PSNR (dB) for various techniques

Methods	Pelvis	Chest	Head	Neck	Thorax
Histogram Equalisation	14.28	11.82	13.29	14.07	8.3
CLAHE	19.01	17.03	19.28	20.71	24.91
Negation	35.68	10.69	3.67	7.3	1.05
Solarisation	17.5	42.59	14.76	32.36	24.73
Proposed Method	17.79	16.94	19.08	20.46	24.5

4.8. Entropy

Entropy of image is maximum when gray levels are distributed uniformly i.e. with equal probabilities. [1] Low entropy indicates low image quality and less information content while higher values indicate images which are richer in details. The entropy, H of a two-dimensional gray-scale image can be defined as:

$$\mathrm{H(X)} = -\sum_{x} p(x) \times \log p(x) \tag{9}$$

Where p(x) is the probability of the occurrence of a pixel.

Table 8. Entropy, H (bits/pixel) for various techniques

Methods	Pelvis	Chest	Head	Neck	Thorax
Original Image	7.25	5.79	6.55	6.67	4.75
Histogram Equalisation	5.77	5.63	3.93	3.07	4.1
CLAHE	5.32	4.04	4.98	3.71	3.75
Sharpening (default)	6.76	6.09	6.4	6.65	4.63
Negation	5.02	3.67	4.45	3.47	4.13
Solarisation	6.87	5.93	5.93	6.42	4.47
Log Transformation	4.65	2.51	4.27	2.67	1.54
Proposed Method	6.62	6.89	6.82	7.34	5.07

4.9. Structural Content

Considering x (i,j) as the original image and y (i,j) as the modified image, structural content is mathematically defined as [12],

$$\text{Structural Content} = \frac{\sum_{j=1}^{M}\sum_{k=1}^{N} y_{j,k}^2}{\sum_{j=1}^{M}\sum_{k=1}^{N} x_{j,k}^2} \tag{10}$$

If the value of SC is large, it indicates poor quality of image.

Table 9. Structural Content for various techniques

Methods	Pelvis	Chest	Head	Neck	Thorax
Histogram Equalisation	0.743	1.174	0.272	0.592	1.37
CLAHE	0.371	0.543	0.321	0.57	0.938
Negation	0.266	0.647	0.225	0.653	2.141
Log Transformation	0.311	0.45	0.523	0.261	0.874
Solarisation	0.328	0.606	0.248	0.639	0.939
Gamma = 0.5	0.312	0.496	0.283	0.553	0.892
Gamma = 2	0.461	0.638	0.377	0.66	0.954
Proposed Method	0.399	0.543	0.32	0.57	0.938

4.10. Average Difference

It indicates the deviation of pixel values of processed image from the original image. It is mathematically defined as,

$$\text{Average Difference} = \frac{\sum_{j=1}^{M}\sum_{k=1}^{N} x_{j,k} - x'_{j,k}}{\text{MN}} \tag{11}$$

Larger the average difference, poorer the image quality. Typically, a negative average difference value means that, overall, the intensities of the modified image are higher than the corresponding original image. [12]

Table 10. Average Difference for various techniques

Methods	Pelvis	Chest	Head	Neck	Thorax
Histogram Equalisation	-18.39	31.53	-104.4	-42.14	42.76
CLAHE	-68.03	-52.51	-76.07	-53.08	-11.48
Negation	-118.4	-23.57	-130.3	-28.11	112.38
Log Transformation	-92.04	-76.94	-62.79	-98.06	-22.07
Solarisation	-85.56	-31.85	-107.5	-29.94	-9
Gamma = 0.5	-95.4	-65.3	-93.31	-57.77	-20.14
Gamma = 2	-25.13	-21.5	-50.5	-21.3	-2.55
Proposed Method	-61.16	-52.5	-75.8	-52.76	-11.5

4.11. Normalised Cross Correlation

NK is used to check similarity between two images. NK conveys the degree to which the two images are correlated. Mathematically it is given as,

$$\text{NK} = \frac{\sum_{j=1}^{M}\sum_{k=1}^{N} x_{j,k}x'_{j,k}}{\sum_{j=1}^{M}\sum_{k=1}^{N} x_{j,k}^2} \tag{12}$$

Table 11. Normalised Cross Correlation for various techniques

Methods	**Pelvis**	**Chest**	**Head**	**Neck**	**Thorax**
Histogram Equalisation	1.039	0.8412	1.3894	1.1924	0.8276
CLAHE	1.409	1.3173	1.1228	1.2473	1.0187
Negation	1.633	1.1382	1.2304	1.0763	0.4397
Log Transformation	1.569	1.466	1.315	1.442	1.046
Solarisation	1.41	1.19	0.94	1.112	1.004
Gamma = 0.5	1.572	1.39	1.34	1.278	1.039
Gamma = 2	1.16	1.13	0.81	1.06	1
Proposed Method	1.366	1.32	1.12	1.25	1.02

4.12. Normalised Absolute Error

NAE measures how close the processed image is to the original one. It is mathematically given as,

$$\text{NAE} = \frac{\sum_{j=1}^{M}\sum_{k=1}^{N} \mid x_{j,k} - x'_{j,k} \mid}{\sum_{j=1}^{M}\sum_{k=1}^{N} \mid x_{j,k} \mid} \tag{13}$$

The larger the value of NAE, poorer the quality of image.

Table 12. Normalised Absolute Error for various techniques

Methods	**Pelvis**	**Chest**	**Head**	**Neck**	**Thorax**
Histogram Equalisation	0.477	0.348	1.39	0.49	0.196
CLAHE	0.754	0.384	1.326	0.42	0.064
Negation	1.284	0.492	1.965	0.56	0.613
Log Transformation	0.996	0.511	0.473	1.42	0.104
Solarisation	1.107	0.465	2.11	0.53	0.106
Gamma = 0.5	1.032	0.43	1.323	0.41	0.093
Gamma = 2	0.845	0.513	1.513	0.58	0.078
Proposed Method	0.679	0.385	1.329	0.42	0.064

4.13. Maximum Difference

MD is mathematically given as,

$$\text{MD} = max \mid x_{j,k} - x'_{j,k} \mid \tag{14}$$

Table 13. Maximum Difference for various techniques

Methods	**Pelvis**	**Chest**	**Head**	**Neck**	**Thorax**
Histogram Equalisation	227	141	157	165	142
CLAHE	46	110	226	123	78
Negation	52	146	178	230	255
Log Transformation	26	146	119	227	80
Solarisation	125	158	218	174	148
Gamma = 0.5	5	113	207	90	63
Gamma = 2	71	178	230	177	88
Proposed Method	55	111	226	124	79

4.14. Pearson Correlation Coefficient

Pearson correlation co-efficient is denoted by and it measures the correlation. Mathematically, it is defined as:

$$\rho_{X,Y} = \frac{\text{cov }(X,Y)}{\sigma_X \times \sigma_Y} \tag{15}$$

4.15. Universal Image Quality Index

This parameter is 'universal' as it does not depend on viewing conditions. The best value is 1; though the dynamic range is [-1,1]. It accounts for loss of correlation, luminance distortion and contrast distortion in one parameter. [13] Mathematically,

$$\text{Q.I} = \frac{4 \times \sigma_{X,Y} \times \bar{x} \times \bar{y}}{(\sigma_x^2 + \sigma_y^2)(\bar{x}^2 + \bar{y}^2)} \tag{16}$$

4.16. Mean Absolute Error

MAE is used to measure how close the pro-cessed images are to the original images and is given by:

$$\text{MAE} = \frac{\sum_{i=1}^{n} \mid f_i - y_i \mid}{n} \tag{17}$$

where f_i is the processed and y_i the true image.

4.17. Enhancement Measurement Error

EME is used to measure the level of enhancement obtained using a given enhancement algorithm. Higher EME means more contrast and a visually pleasing image. Mathematically,

$$EME = \frac{\sum_{m=1}^{k} \sum_{l=1}^{k} 20 \ln \left(\frac{I_{max}}{I_{min}} \right)}{k^2} \tag{18}$$

4.18. Signal to Noise Ratio

SNR describes the ability of the digital system to convert the electric signal into a useful radiographic image. The more signal that is present, the less noise, the higher the quality of the image. Negative SNR indicates that noise is more than the signal. [7]

5. EXPERIMENTAL RESULTS AND DISCUSSIONS

Image enhancement is necessary to provide a better representation of the radiotherapy images. The imaging parameters before and after application of various operations, were compared for 5 DICOM EPI images. To quantify the degree of enhancement or degradation experimentally, metrics like mean, variance, standard deviation, MSE, RMSE, entropy, PSNR, AMBE, normalised cross correlation, average difference, structural content (SC), maximum difference and normalised absolute error (NAE) are compared. It is found that PSNR is improved with the CLAHE method in comparison with HE and the proposed algorithm improves the appearance of the EPI details significantly in terms of visual quality and preservation of edges. By adding salt and pepper noise, Gaussian noise and motion blur, we calculate error measurement parameters like PSNR, MSE, RMSE, UIQ index, Enhancement Measurement Error (EME), Pearson Correlation Coefficient, SNR, Mean Absolute error (MAE) as illustrated in Tables 14, 15, 16. It is observed that Gaussian and Salt and Pepper noise degrade the images beyond recognition.

Table 14. Image error measurements by adding salt and pepper noise (σ = 0.05)

Parameters	**Pelvis**	**Chest**	**Head**	**Neck**	**Thorax**
PSNR (dB)	18.09	18.74	17.5	18.08	16.48
MSE	1017.9	876.2	1164.3	1019.2	1472.5
RMSE	31.9	29.6	34.1	31.92	38.37
UIQ index	0.061	0.068	0.181	0.083	0.163
EME (original)	1.889	1.315	6.044	1.647	1.849
EME (noisy)	3.842	1.872	4.556	1.562	1.218
PCC (original v/s noisy)	112899	32922	153449	29514	273659
PCC (original v/s original)	167075	64979	173051	38219	318189
SNR (dB)	-6.029	-5.361	-8.437	-6.017	-7.646
MAE	6.349	6.349	6.35	6.69	6.44

Table 15. Image error measurements by adding Gaussian noise (σ = 0.05)

Parameters	**Pelvis**	**Chest**	**Head**	**Neck**	**Thorax**
PSNR (dB)	14.03	13.5	14.34	13.78	15.47
MSE	2585.4	2992	2408.9	2741.4	1859.9
RMSE	50.84	54.06	49.08	52.35	43.12
UIQ index	0.0049	0.0084	0.0402	0.0127	0.01991
EME (original)	1.889	1.315	6.044	1.647	1.85
EME (noisy)	5.225	37.67	12.86	27.1	16.03
PCC (original v/s noisy)	79037	19625	134302	22322	263181
PCC (original v/s original)	167075	64979	173051	38219	318189
SNR (dB)	-10.08	-10.59	-11.59	-10.31	-8.66
MAE	41.05	44	36.03	42.29	27.93

Table 16. Image error measurements by adding Motion Blur (σ = 0.05)

Parameters	**Pelvis**	**Chest**	**Head**	**Neck**	**Thorax**
PSNR (dB)	40.75	37.78	27.48	31.31	29.54
MSE	5.501	10.91	116.88	48.48	72.71
RMSE	2.34	3.3	10.81	6.96	8.52
UIQ index	0.449	0.636	0.622	0.58	0.34
EME (original)	1.89	1.315	6.044	1.647	1.849
EME (noisy)	0.99	0.896	5.97	1.275	1.54
PCC (original v/s noisy)	79037	19625	134302	22322	263181
PCC (original v/s original)	166590	63959	170882	37670	315692
SNR (dB)	16.64	13.68	1.54	7.2	5.42
MAE	1.54	2.12	4.29	3.189	2.657

5. CONCLUSION

To get refined in-treatment electronic portal images in order to extract relevant features of the anatomy, we inspected several image processing techniques for contrast enhancement, de-noising and edge detection/sharpening. The imaging parameters before and after application of various operations, were compared for 5 EPI images in DICOM format. To quantify the degree of enhancement or degradation experimentally, metrics like mean, variance, standard deviation, MSE, RMSE, entropy, PSNR, AMBE, normalised cross correlation, average difference, structural content (SC), maximum difference and normalised absolute error (NAE) are compared. The work of robust automated registration of Digitally Reconstructed Radiograph (DRR) and electronic portal image using landmark points is underway. Many processes like edge detection, image registration, image enhancement, etc. are planned to be made faster using Graphics Processing Unit (GPU).

ACKNOWLEDGEMENTS

The authors would like to acknowledge Dr. Sudesh Deshpande, Medical Physicist from Hinduja Hospital, Mumbai for his contribution of electronic portal images in this study.

REFERENCES

[1] A.K Jain, A Guide to Fundamentals of Digital Image Processing, University of California Davis.
[2] Rafael C. Gonzalez and Richard E. Woods, Digital Image Processing, 2nd ed. Prentice Hall, 2002.
[3] Alasdair Mc Andrew, Introduction to Digital Image Processing with Matlab, India ed.
[4] Larry E Antonuk, (2002) "Electronic Portal Imaging Devices: a review and historical perspective of contemporary technologies and research", Physics in Medicine and Biology, R31R65.
[5] Michael G. Herman, Jon Kruse and Christopher Hagness, (2000) "Guide to clinical use of electronic portal imaging," Journal Of Applied Clinical Medical Physics, Vol. 1, Number 2, pp 38-57.
[6] Lawrence E. Reinstein, (1987) "Radiotherapy Portal Imaging Quality," AAPM, USA. New York, Report 24.
[7] Sanjiv Samant, Wu. J and Zhen. W, (2000) "Automated Edge Detection: New Methodologies for Portal Imaging," Proceedings of the 22nd Annual EMBS International Conference, Chicago.
[8] Alireza Shirazi, Seied Rabie Mahdavi, Dariush Sardari and Lida Sadri, (2006) "Portal Image Contrast Enhancement," Rep Pract Oncol Radiother, Iran, pp 23-28.
[9] Konstantinos Koutsofios, Nikoletopoulos. S, Episkopakis and Kandarakis, (2006) "Sequential Contrast Enhancement of Portal Images: Study of the Influence on Image Quality and Clinical Usefulness," IEEE Nuclear Science Symposium Conference Record, Greece, pp 2629-2631.
[10] Mao-Hsiung Hung, Shu-Chuan Chu, John F. Roddick, Jeng-Shyang Pan and Chin-Shiuh Shieh, (2010) "An effective Image Enhancement Method for Electronic Portal Images," ICCCI, Part III LNAI 6423, pp 174-183.
[11] Hanan Saleh and Md Nordin, (2011) "Improving Diagnostic Viewing of Medical Images using Enhancement Algorithms," Journal of Computer Science, pp 1831-1838.
[12] Arjun Nichal, Pradnyawant Kalamkar, Amit Lokhande, Vrushali Patil and Bhagyashri Salunkhe, (2013) "A novel approach to medical and gray scale image enhancement," International Journal of Engineering Research and Applications (IJERA), Vol.3, Issue 3, pp 653-657.
[13] Zhou Wang and Alan C. Bovik, (2002) "A Universal Image Quality Index," IEEE Signal Processing Letters.
[14] Geoff Dougherty.: Digital Image Processing for Medical Applications, Cambridge University Press.
[15] Aayesha Hakim, Prof. K.T.Talele, Rajesh Harsh and Dharmesh Verma, (2015) "Electronic Portal Image Processing For High Precision Radiation Therapy," unpublished.
[16] Rashmi, Mukesh Kumar, Rohini Saxena, (2013) "Algorithm and technique on various edge detection: A survey," Signal & Image Processing : An International Journal (SIPIJ) Vol.4, No.3, pp 65-75.
[17] Suman Shrestha, (2014) "Image denoising using new adaptive based median filter," Signal & Image Processing : An International Journal (SIPIJ) Vol.5, No.4, pp 1-13.

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