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A NEW APPROACH FOR CONTRAST ENHANCEMENT IN SPECT IMAGING BASED ON GRADIENT APPROXIMATION AND HISTOGRAM EQUALIZATION (GAHE)

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Abstract

Nuclear medicine is playing a major role in medical diagnosis. But, due to limitations in both injected radionuclide to the patient's body and low count rates of the detector, output images are of very low contrast. Several methods have been proposed to improve the contrast of medical images. In this study, a new method is presented for SPECT images. The proposed method is based on the combination of Gradient Approximation (GA) and Histogram Equalization (HE) algorithms to improve the image contrast. Poisson editing concept is deployed to allow the images to be edited and processed in the gradient domain before the reconstruction phase. GA is initially applied on the images to overcome the limitations of HE method. Using the GA concept, image gradients are manipulated first and then the images are reconstructed. These reconstructed images are fed as input for the HE block. Finally, results are presented both qualitatively and quantitatively.

Keywords:

SPECT, Contrast Enhancement, Histogram Equalization, Gradient Approximation

1. INTRODUCTION

One powerful technique for obtaining diagnostic images of the human body is Single-Photon Emission Computed Tomography, known as SPECT. In the SPECT procedure, the injected radiopharmaceutical is concentrated in specific organs of interest which are further tracked by the SPECT system. Since the acquired three-dimensional data are represented in 2D images, the SPECT imaging system is one of the most powerful tools among nuclear medicine platforms [1].

The contrast in the SPECT images is based on the differences in radionuclide density accumulated in different body parts. So, it is obvious that high contrast leads to an accurate diagnosis. But, there are several factors such as limitations in counting per pixel, the amount of radiopharmaceutical intake, and also differential target tissue absorption, which lead to low contrast in the SPECT imaging systems. Therefore, several research have been conducted on increasing the contrast in nuclear medicine images [2] [3]. Mathematical algorithms and computer aided approach is an inseparable part of the modern medical diagnostics framework. In the recent years, imaging with computer aided algorithm have made remarkable achievement in addressing the variety of challenge in both clinical and industrial disciplines [4] [5]. Some of the major applications are medical image reconstruction, tumor volume detection and evaluation, and treatment planning algorithms optimization [6]. On this basis, in this study, a new method is presented for SPECT images' contrast enhancement using two well-known algorithms: Gradient Approximation (GA) and Histogram Equalization (HE).

Histogram Equalization is a widely-used simple method for contrast improvement which is achieved by normalizing the pixel intensities over a uniformly distributed histogram. In HE, the histogram will be stretched over the regions with high intensity and compressed over the regions with low intensity. In other words, this method expands the histogram of high-intensity areas and compresses low-intensity regions. Although this method is widely used, easily implemented and very effective, it has some problems, some of which are increasing the background noise, decreasing SNR and inability to be locally applied on images, that need to be addressed [7] [8].

The idea behind GA algorithm is that the human eyes are sensitive to gradient rather than intensity. On this basis, Perez et al. [8] presented Poisson editing method [9]. Poisson editing allows the data to be edited and processed in the gradient domain before the reconstruction phase, and the final image can be reconstructed using the gradient. Consequently, the effects of noise, blurring and saturation can be directly manipulated. This method is discussed in detail in various references. The application of this method for contrast enhancement is investigated in [12].

As previously mentioned, HE method has several limitations [7] [8]. So, to improve the contrast enhancement task, a new approach based on the combination of histogram equalization and gradient approximation concepts is proposed. The rest of the paper is organized as follows: gradient approximation and histogram equalization methods are discussed in section 2, the results are disclosed in section 3, and the discussion and conclusion are represented by sections 4 and 5 respectively.

2. MATERIALS AND METHODS

In this study, we use whole body images that are generated using a Siemens SPECT device. Initially, the images were called up in the matlab software and then processed. For the detailed evaluations of the proposed method, HE method was applied once, followed by the application of the proposed method (GA+HE) to the images, and, finally, the results were compared with each other. The following parts of this section describes the proposed method in greater detail.

2.1 GRADIENT APPROXIMATION

Based on the fact that working with the image gradient is easier than working with the image itself [12]-[15], the image gradient in x and y directions are computed using two-dimensional Laplace equation. In this context, let g be the gradient vector of the image, our goal is to find the function f that has the same gradient as the image. Since there could be no function with gradient exactly the same as g, the function f should minimize Eq.(1).

$$\min \iint \|\nabla f - g\|^2 \, dxdy \tag{1}$$

By applying Euler-Lagrange conditions, f should satisfy the Poisson equation which is:

$$\nabla^2 f = \nabla . y \tag{2}$$

The following term should be added to Eq.(1) to keep the details of the image and reduce the non-uniform effects and variance in the image.

$$\iint \left(f - \bar{f} \right)^2 dxdy \tag{3}$$

Knowing that $\bar{f}$ is the image mean, Eq.(3) becomes:

$$\min\left(\iint \|\nabla f - g\|^2 dxdy + \lambda \iint \left(f - \bar{f} \right)^2 dxdy \right) \tag{4}$$

In Eq.(4), λ is the trade-off coefficient that balances the two terms. The gradient calculated at this phase is applied to the original image to further enhance the level of details.

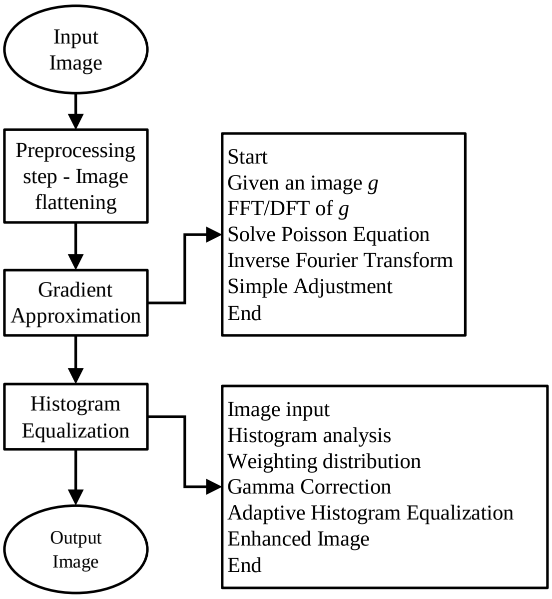

Fig.1. Proposed Method Pipeline

2.2 HISTOGRAM EQUALIZATION

The output image of the last step undergoes histogram equalization. HE is a very common and powerful method that is explained in various resources (ref). Consider the triplet $X = \{x(i, j, l)\}$ as the image with l gray levels. If we show the number of pixels falling in each gray level band with n_k, the histogram of the image can be shown using $H(x)$. Then, the PDF of each band is the quotient of the number of pixels with gray level X_k divided by the total number of pixels.

$$H(X) = \{n_0, n_1, \ldots, n_n, \ldots, n_L\} \tag{5}$$

where, $PDF = n_k/N$.

The cumulative distribution function (CDF) is the sum over all possible PDFs in the image, and the histogram equalization is done according to Eq.(6).

$$C(k) = \sum_{j=0}^{k} PDF(j) \tag{6}$$

Since we want the resulting CDF function to have a uniform and linear behavior, so we compute the following formula:

$$T(i) = \{(G-1)/(a \times b)\} \tag{7}$$

In Eq.(7), $(G-1)$ is the number of gray levels, with a and b as the number of rows and columns respectively.

The pipeline of the proposed method is illustrated in Fig.1. To reduce the processing time and implementing the algorithm more conveniently, images are first converted to the one-dimensional array in the preprocessing step.

3. RESULTS

In this study, the steps shown in Fig.1 are applied to the whole body SPECT images. The whole process can be divided into two phases: in the first phase, a more detailed image is reconstructed based on the gradient of the image using GA algorithm; and, these images are used as the inputs for the second phase where they are histogram equalized. Finally, the whole method is performed without the GA phase for a better understanding of the role of GA algorithm in accomplishing the contrast enhancement.

In Fig.2(a), the low-contrast original whole body image is shown. The output of the second phase is then illustrated in Fig.2(b) together with its histogram as H_b. It is visually apparent that this image has better visual quality than the original image. In the last step, the histogram equalized image is shown in Fig.2(c). The final image has apparently higher contrast and much more details. The same results for the pelvis and rib cage SPECT images are illustrated in Fig.3 and Fig.4 respectively, and the results support the results in Fig.1(a) - Fig.1(c).

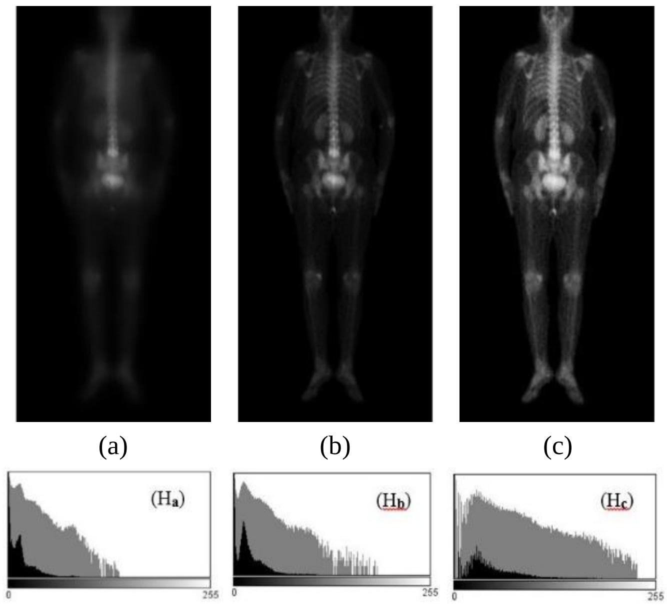

Fig.2. (a) The original whole body SPECT image, with Ha as its histogram; (b) The reconstructed image from the second gradient using GA algorithm, with H_b as its histogram; (c) The output image of the pipeline in Fig.1, with H_c as its histogram.

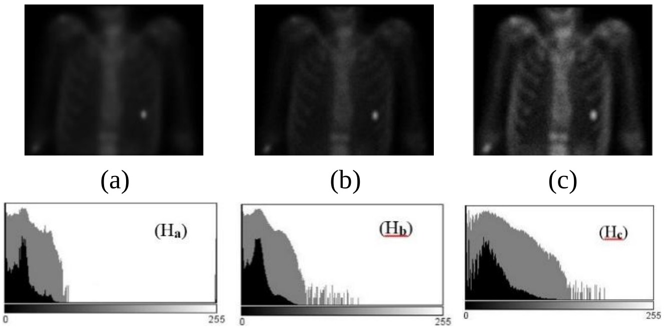

Fig.3. (a) The original Rib Cage SPECT image, with Ha as its histogram; (b) The reconstructed image from the second gradient using GA algorithm, with H_b as its histogram; (c) The output image of the pipeline in Fig.1, with H_c as its histogram

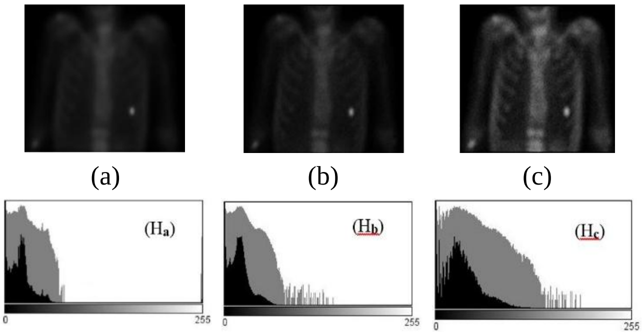

Fig.4. (a) The original Pelvis SPECT image, with Ha as its histogram; (b) The reconstructed image from the second gradient using GA algorithm, with H_b as its histogram; (c) The output image of the pipeline in Fig.1, with H_c as its histogram

For quantitative performance evaluation, PSNR and MSE measures are computed for ten images with and without the application of GA algorithm (Table.1). These results indicate that applying the full workflow of the proposed method leads to PSNR and MSE increase and decrease. In Table.2, the performance of the GA algorithm has been evaluated in terms of IQI, SNR, PSNR, and MSE measures. According to these results, the method has acceptable performance in improving the image quality.

Table.1. PSNR and MSE for the proposed method and the method without applying GA algorithm

Samples	Proposed Method		HE	
	PSNR	MSE	PSNR	MSE
Image #1	36.048	432.875	20.2018	651.05
Image #2	35.984	602.804	19.4165	971.03
Image #3	34.650	476.653	18.761	420.41
Image #4	30.764	611.746	15.238	112.09
Image #5	33.537	544.761	16.064	849.3585

The Fig.5 compares the contrast enhancement efficiency of the proposed method to the results of applying the histogram equalization method alone.

Table.2. SNR, PSNR, IQI, and MSE for the GA algorithm

Samples	SNR	PSNR	IQI	MSE
Image #1	3.23	30.764	0.6312	611.746
Image #2	3.082	29.808	0.6754	537.910
Image #3	3.607	34.650	0.53901	476.653
Image #4	2.84	31.983	0.60148	471.324
Image #5	3.049	27.329	0.58773	503.812
Image #6	4.509	36.048	0.69156	432.875
Image #7	3.982	32.183	0.6578	593.650
Image #8	4.873	35.984	0.61091	602.804
Image #9	4.092	31.137	0.5847	498.900
Image #10	3.640	33.537	0.60845	544.761

4. DISCUSSION

Nuclear medicine is playing a major role in medical diagnosis. But due to limitations in both injected radionuclide to the patient's body and low count rates of the detector, output images are of very low contrast. For this study, we have used the whole body SPECT images. To obtain these images, tc99-MDP is administered. It is necessary to notice that beside the contrast limitations which is stated before, tc99-MDP/Kg and also patient's age are other factors affecting the contrast. To improve image contrast, in this study, we have represented the method based on the combination of gradient approximation and histogram equalization algorithms. To overcome the limitations of HE method, we have initially applied GA on the images. Using the GA concept, image gradients were manipulated first and then images were reconstructed. These reconstructed images are the inputs of HE block. For instance, the Fig.1(c) is the final image after applying our proposed method, which compared to the original image Fig.1(a), obviously has higher contrast and more useful details. So, it has remarkable clinical benefits which enable us to use them in diagnostic and therapeutic procedures. Also, Fig.2 and Fig.3 indicate the optimal performance of the proposed algorithm.

Kumar Pandey et.al [16] have applied GHE on WBB images with very low contrast, and they proved that the contrast of these images significantly improved. They also pointed out that GHE can be useful in combination with other processing techniques. Therefore in this study, we have investigated the application of HE in combination of GA algorithm in the same area. The HE method was applied to the images both individually and in combination with the GA method. Along with the observations and findings in [16] have revealed that the combination of HE and GA has a great effect on the improvement of the contrast of nuclear medicine images.

In another study, Abdallah and Wagiallah [17] utilized MATLAB software and image processing tools to reduce noise and improve the contrast of WBB images. Likewise, this study is based on this software and its capabilities.

We combined two different algorithms to improve the contrast in medical images. Moreover, Asamoah et al. [18] used SNR, PSNR and MSE criteria to compare the HE method with AHE and CLAHE methods. As a result, they introduced the HE technique as an effective method to improve the contrast of images. In this study, in order to evaluate the performance of the proposed algorithm quantitatively, the same criteria has been used. As shown in Table.1 and Fig.5, compared with the HE method, the PSNR values increased and MSE decreased and the images showed significant improvement in terms of contrast and visual quality. Additionally, to investigate the behavior of GA algorithm quantitatively, SNR, PSNR, IQI and MSE criteria were obtained for 10 different images (Table.2). As can be seen, the method presented in this study has significantly improved SNR and PSNR values, as well as IQI.

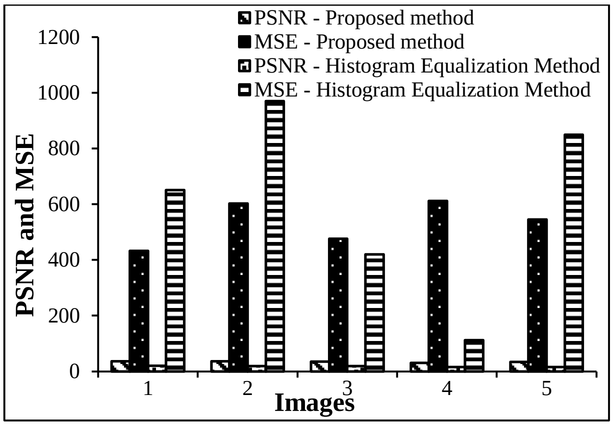

Fig.5. MSE and PSNR calculated for the results of applying GA+HE method compared to the results of HE method

5. CONCLUSION

The method implemented in this paper can be applied to different image categories: colored, satellite, medical, etc. By applying GA method before HE, the method becomes very robust against noise, blurring and saturation in images as we can manipulate the image quality in the gradient domain. It should be noted that post-processing could have profound diagnostic advantages in clinical settings.

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