Using FC-CLAHE-ADF to enhance digital mammograms for detecting breast lesions

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Abstract. Digital mammograms are commonly used for breast screening, especially to aid the detection of cancer. However, digital mammograms suffer with low contrast images due to the low exposure factors used. This paper presents a novel image enhancement technique for digital mammogram images known as Fuzzy Clipped Contrast-Limited Adaptive Histogram Equalization with Anisotropic Diffusion Filter (FC-CLAHE-ADF). This proposed FC-CLAHE-ADF has adopted a fuzzy-based and histogram-based image enhancement technique where it can further reduce the noise of the digital mammograms while preserving the contrast and brightness. A total of six digital mammograms were retrieved from Mammographic Image Analysis Society (MIAS) open-source database. The performance of FC-CLAHE-ADF was compared to Recursive Mean-Separate Histogram Equalization (RMSHE), Fast Discrete Curvelet Transform via Unequally Spaced Fast Fourier Transform (FDCT-USFFT), and FC-CLAHE only. In summary, this novel FC-CLAHE-ADF has provided the most superior results, among other selected enhancement techniques. The resulting images have been able to demonstrate breast lesions better.

Keywords: digital image processing, fuzzy inference system, histogram equalization, mammography

1. Introduction
One of the main causes of death among women is breast cancer [1,2]. Digital mammograms are used at an early stage to screen and diagnose breast cancer [3]. In previous studies, they have shown that the early screening of breast cancer improves breast cancer survival [4–6]. However, digital mammograms suffer with low contrast images due to the low exposure factors used. Therefore, the image enhancement technique is required to improve the current image quality.

Image enhancement techniques are used to highlight the details and enhance any suspected abnormalities in the images [7]. These techniques involve manipulation of contrast and intensity appearances. In previous, various mammographic image enhancement techniques have been introduced, such as histogram-based, frequency-based, fuzzy-based, and filter-based. Examples of those techniques are Histogram Equalization (HE) [8], Contrast Limited Adaptive Histogram Equalization (CLAHE) [9,10], Recursive Mean-Separate Histogram Equalization (RMSHE) [11], fuzzy logic based enhancement [10,12–14], Fast Discrete Curvelet Transform via Unequally Spaced Fast Fourier
Transform (FDCT-USFFT) [15] and nonlinear unsharp masking [16]. However, these image enhancement techniques still have limitations such as high computational burdens and image noise [17].

A novel image enhancing technique has been proposed in this paper for digital mammograms known as Fuzzy Clipped Contrast-Limited Adaptive Histogram Equalization with Anisotropic Diffusion Filter (FC-CLAHE-ADF).

2. Materials and methods

2.1. Image database

A total of six digital mammograms were retrieved from Mammographic Image Analysis Society (MIAS) open-source database [18]. The image size of each image datasets is 1024 X 1024 pixels. Table 1 shows digital mammograms with various background tissues and abnormalities.

| Condition | Image | Background tissue | Abnormality |
|-----------|-------|-------------------|-------------|
| Normal    | 1     | Fatty             | Normal      |
|           | 2     | Fatty             | Normal      |
| Benign    | 3     | Fatty             | Architectural distortion |
|           | 4     | Fatty-glandular   | Asymmetry   |
| Malignant | 5     | Fatty             | Spiculated masses |
|           | 6     | Fatty-glandular   | Circumscribed masses |

2.2. Fuzzy Clipped Contrast-Limited Adaptive Histogram Equalization with Anisotropic Diffusion Filter (FC-CLAHE-ADF)

Contrast-Limited Adaptive Histogram Equalization (CLAHE) is one of the derivation methods in Histogram Equalization (HE)-based. CLAHE divides the input images into several non-overlapping sub-images and clips them to limit the amount of image enhancement. The clipped histogram changes the structure of the input images by reducing or increasing the values with reference to the threshold or the clipping limit before the equalization. The input images are clipped and calculated by using Equation (1).

\[
Clip\ Limit = \left\lfloor \frac{\phi}{256} \right\rfloor + \left\lfloor \beta \cdot (\phi - \left\lfloor \frac{\phi}{256} \right\rfloor) \right\rfloor
\]

Where \(\beta\) is the clipping enhancement parameter and \(\left\lfloor . \right\rfloor\) denotes the truncating value to the nearest integer. The \(\phi\) is a product of block size. The value of 256 denotes the pixel intensity values range from 0 to 255.

FC-CLAHE-ADF is derived from the CLAHE technique. This FC-CLAHE-ADF technique consists of a fuzzy clipped inference system, which automates clip-limit selection. ADF is used to reduce the noise of the mammographic images while preserving the details. The flowchart of the proposed FC-CLAHE-ADF enhancement technique is shown in Figure 1.

Fuzzy Clipped (FC) Interface System has been set up with two input measures, which include the contrast (C) and the discrete entropy (E). The output measure of FC is the fuzzy clipping enhancement parameter (f\(\beta\)). The fuzzy sets of (C) are Low (V1), Medium (V2), and High (V3), while (E) are Small (W1) and Big (W1). The values for V1, V2, V3, W1, and W2 were fixed using ground truth or knowledge base benchmark datasets. Triangular membership function was used to construct the rules of FC and classify the f\(\beta\) into clip limit low (CL1) and clip limit high (CL2). The value of each rule for overall FC output was aggregated into a single fuzzy set. The result of the defuzzification of FC is 0.0191. As a result, the f\(\beta\) is 0.0119 for the given values of (C = 0.4) and (E = 0.4). The f\(\beta\) varies between 0 and 0.1. The FC-CLAHE method uses Equation (2) to calculate the new clip limit that depends on the C and E of the input images.
\[ Fuzzy \ Clip \ Limit = \left[ \frac{\varphi}{256} \right] + \left[ f\beta \left( \varphi - \left[ \frac{\varphi}{256} \right] \right) \right] \] (2)

Where \( f\beta \) is the fuzzy clipping enhancement parameter (ranges from 0 to 0.1) and \([ \cdot]\) denotes the truncating value to the nearest integer. \( \varphi \) is the product of block size. The value of 256 denotes the pixel intensity values range from 0 to 255.

Anisotropic diffusion filter (ADF) was used to remove the noise and preserve the details by using a partial differential equation. The model of ADF is introduced by Perona and Malik [19]. The anisotropic coefficient is used to stop the diffusion over the edges of the image [20]. Equation (3) describes the ADF model.

\[ \frac{\partial I(x,y)}{\partial t} = div(g(|\nabla I(x,y)|)\nabla I(x,y)) \] (3)

Where \( div(.) \) and \( \nabla \) represent the divergence and the gradient operators respectively, while \( g(|\nabla I(x,y)|) \) is a reducing function known as an edge stop mechanism, which plays an important role in regulating the mechanism of diffusion. Another two decreasing functions can be described in Equation (4).

\[ g'(|\nabla I(x,y)|) = \frac{1}{1 + \frac{|\nabla I(x,y)|^2}{k^2}} \]  
\[ g''(|\nabla I(x,y)|) = \exp (-|\nabla I(x,y)|^2/k^2) \] (4)

Where \( k \) is a parameter with a threshold role. If \( |\nabla I| > k \) so the pixels are considered edges and will be less blurred. On the other hand, if \( |\nabla I| \leq k \), the pixels are considered as the interior region and will be highly smoothed.

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**Figure 1.** Flowchart of the proposed FC-CLAHE-ADF enhancement technique.
3. Results and Discussion

The resulting images of various image enhancement techniques are shown in Figure 2. The enhanced digital mammograms have shown superior image quality than the original images. The enhanced digital mammograms have preserved the details for the interpretation of breast lesions.

Figure 2 (a) has shown the original image of digital mammograms with low contrast features. The details of dense tissue in the breast are reduced in the images. The details, such as breast textures, edges, and lines, are blurred and grainy. The low contrast and low intensity could affect the detection of potential tumors as they could reside within dense tissues. Figure 2 (b) and (d) have shown the enhanced images by RMSHE and FC-CLAHE, respectively. Both of these techniques have shown improvement but are overly enhanced, which leads to noise amplification.

The enhanced images produced by FDCT-USFFT in Figure 2 (c) have shown no improvement even after the enhancement process. The proposed FC-CLAHE-ADF in Figure 2 (e) has shown appropriate noise reduction while preserving the details. FC-CLAHE-ADF has produced digital mammograms without overly enhanced as compared to other techniques. Therefore, the proposed FC-CLAHE-ADF could assist in the identification of breast lesions, especially for early breast cancer detection.
4. Conclusion
A novel of FC-CLAHE-ADF has been proposed for digital mammograms. The overall quality of enhanced images has been improved as compared to the other techniques such as RMSHE, FDCT-USFFT, and FC-CLAHE only.

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