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Contrast enhancement and brightness preserving of digital mammograms using fuzzy clipped contrast-limited adaptive histogram equalization algorithm

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ABSTRACT

A novel fuzzy logic and histogram based algorithm called Fuzzy Clipped Contrast-Limited Adaptive Histogram Equalization (FC-CLAHE) algorithm is proposed for enhancing the local contrast of digital mammograms. A digital mammographic image uses a narrow range of gray levels. The contrast of a mammographic image distinguishes its diagnostic features such as masses and micro calcifications from one another with respect to the surrounding breast tissues. Thus, contrast enhancement and brightness preserving of digital mammograms is very important for early detection and further diagnosis of breast cancer. The limitation of existing contrast enhancement and brightness preserving techniques for enhancing digital mammograms is that they limit the amplification of contrast by clipping the histogram at a predefined clip-limit. This clip-limit is crisp and invariant to mammogram data. This causes all the pixels inside the window region of the mammogram to be equally affected. Hence these algorithms are not very suitable for real time diagnosis of breast cancer. In this paper, we propose a fuzzy logic and histogram based clipping algorithm called Fuzzy Clipped Contrast-Limited Adaptive Histogram Equalization (FC-CLAHE) algorithm, which automates the selection of the clip-limit that is relevant to the mammogram and enhances the local contrast of digital mammograms. The fuzzy inference system designed to automate the selection of clip-limit requires a limited number of control parameters. The fuzzy rules are developed to make the clip limit flexible and variant to mammogram data without human intervention. Experiments are conducted using the 322 digital mammograms extracted from MIAS database. The performance of the proposed technique is compared with various histogram equalization methods based on image quality measurement tools such as Contrast Improvement Index (CII), Discrete Entropy (DE), Absolute Mean Brightness Coefficient (AMBC) and Peak Signal-to-Noise Ratio (PSNR). Experimental results show that the proposed FC-CLAHE algorithm produces better results than several state-of-art algorithms.

1. Introduction

Breast Cancer is the most frequently diagnosed cancer in women [1]. Mammography is proven to be one of the effective diagnostic tools for early detection of breast cancer. A digital mammographic image uses a narrow range of gray levels. The histogram structure of digital mammograms is not well-defined. Both non-cancerous and cancerous breast masses appear as white regions in mammographic films. The fatty tissues appear as black regions. The other components of the breast, such as glands, connective tissue, tumors and calcium deposits appear as shades of gray, more toward the brighter intensity on a digital mammogram [2]. These varied representations of gray levels make digital mammograms as difficult images to interpret. A large number of digital mammograms generated each year need accurate and fast interpretation of images. Non-cancerous lesions can be misinterpreted as a cancer (false-positive value), while cancers may be missed (false-negative value). As a result, radiologists fail to detect 10–30% of breast cancers [3]. Computer aided diagnostic (CAD) systems can help radiologists in accurate interpretation of digital mammograms. The first step in the CAD system for the analysis of digital mammogram images involves pre-processing of the images for contrast enhancement while preserving the brightness of the images.

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The contrast enhancement and brightness preserving techniques should not deteriorate or destroy the information content in the image for fast and accurate interpretation of digital mammograms. Thus, contrast enhancement and brightness preserving of digital mammograms is very important for early detection and further diagnosis of breast cancer. The fundamental enhancement needed in mammography is an increase in contrast. Contrast between malignant tissue and normal dense tissue may be present on a mammogram, but below the threshold of human perception [4]. Several works have been done in the past for contrast enhancement using histogram equalization of images [5–9]. Generally, histogram equalization stretches the contrast of the high histogram regions, and compresses the contrast of the low histogram regions [10]. As they push the intensities toward the extreme right or the extreme left side of the histogram it causes level saturation effects and when the region of interest occupies a small portion of the image it will not be properly enhanced.

As the digital mammograms are textural images, contrast enhancement of these images using the conventional algorithms is very difficult. Adaptive Unsharp Masking (USM) [11] was applied for contrast enhancement. It also lacks in detecting low contrast edges in digital mammograms. Dynamic Histogram Equalization (DHE) [12], is used to eliminate the domination of higher histogram components on lower histogram components in the image histogram and to control the amount of stretching of gray levels for reasonable enhancement of the image features by using local minima separation of histogram. Brightness Preserving Dynamic Histogram Equalization (BPDHE) is an extension method of the DHE and Multi Peak Histogram Equalization with Brightness Preserving (MPHEBP) and this technique divides the input histogram based on local maximum value [13]. BPDHE shown better contrast enhancement compared to MPHEBP and mean brightness preserving compared to DHE.

Research [14–30] shows various contrast enhancement methods based on histogram equalization and fuzzy techniques. The research on contrast enhancement of digital mammograms [31,32] using adaptive neighborhood methods are also not immune to noise and produces more artifacts. Contrast improvement technique proposed by Rangayyan et al. [33] improves the contrast of the mammogram image while compromising the naturalness of the original image. Kim et al. [34] used first derivative and local statistics to enhance mammograms. This method could not handle the texture nature of mammogram images. It is more suitable for low degree of gray level discontinuities. Partitioned iterated function systems (PIFS) proposed by Economopoulos et al. [35] is also not suitable for contrast enhancement of digital mammograms because it produces more artifacts.

The contrast limited adaptive histogram equalization (CLAHE) algorithm proposed by Zuiderveld et al. [36] has very good results for contrast enhancement of digital mammograms. But it is also not suitable for images of very fine details. Sundaram et al. [37] proposed histogram modified local contrast enhancement (HM-LCE) for mammogram images. This method brings out the local details present in the original image for more relevant interpretation but hidden information is not significantly enhanced. From the literature survey done, it is evident that contrast enhancement without losing relevant information and without artifacts while preserving the naturalness of the original mammogram still remains a challenge. The proposed Fuzzy Clipped Contrast-Limited Adaptive Histogram Equalization (FC-CLAHE) algorithm enhances the local contrast of digital mammograms while preserving the brightness of the mammogram. The contrast is sufficiently enhanced to make the diagnosis more accurate. Clipped Histogram Equalization (CHE) [38–41] methods are used to overcome these problems by restricting the enhancement rate. Clipped Histogram Equalization technique modifies the shape of the histogram of the input images by minimizing or increasing the value in the histogram's bins based on a threshold limit before the equalization process. The clipped portion will be redistributed back to the histogram and then histogram equalization is carried out. Clipped Histogram Equalization is far more effective for contrast enhancement than the existing histogram equalization based methods. The major drawbacks of the Clipped Histogram Equalization method are that these methods require manual setting of plateau level of the histogram which is not suitable for automatic systems and some of the methods put weight to the modified histogram. The weight factor also depends on the user.

The proposed FC-CLAHE algorithm is based on the observation that the existing histogram equalization techniques limits the amplification of contrast by clipping the histogram at a predefined value called clip-limit. This clip-limit is crisp and invariant to image data. This causes all the pixels inside the window region of the image to be equally affected. Higher values of clip limit result in more contrast and hence this algorithm is not very suitable for real time applications. The proposed algorithm automates the selection of clip-limit which makes it flexible and variant to image data. A fuzzy inference system is designed to automate the selection of clip-limit with a limited number of control parameters. The fuzzy rules are developed to make the clip limit flexible and variant to mammogram data without human intervention. Experiments are conducted using the 322 digital mammograms extracted from MIAS database. Various histogram equalization methods are compared with image quality measurement tools such as Contrast Improvement Index (CII), Discrete Entropy (DE), Absolute Mean Brightness Coefficient (AMBC) and Peak Signal-to-Noise Ratio (PSNR). Subjective evaluation is done with expert radiologists. Experimental results show that the proposed FC-CLAHE algorithm produces better enhanced images than several state-of-art algorithms.

2. Proposed FC-CLAHE method

2.1. Histogram equalization

For a given image $X = \left\{X(i,j)\right\}$ with L discrete gray levels denoted as $\left\{X_0, X_1, \ldots, X_{L-1}\right\}$, the probability density function, $p(X_k)$ is given by:

$$p(X_k) = \frac{N_k}{N}, \qquad \text{for } k = 0, 1 \ldots, L-1 \tag{1}$$

where N_k represents the number of times the level X_k appears in the input image X and N is the total number of samples in the input image. L is the number of gray levels ($L = 256$) of the given image.

Then, the cumulative density function, $c(x)$ is defined by

$$c(X_k) = \sum_{j=0}^{k} p(X_j) \qquad \text{for } k = 0, 1 \ldots, L-1 \tag{2}$$

where $x = 0, 1, \ldots, L-1$. Histogram equalization is a scheme that maps the input image into the entire dynamic range (X_0, X_{L-1}) by using the cumulative density function as a transform function. The transformation function $f(x)$ based on the cumulative density function is given as:

$$f(x) = X_0 + (X_{L-1} - X_0).c(x) \tag{3}$$

where (X_{L-1}) represents the maximum gray level. The output image produced by histogram equalization is expressed as

$$Y = f(x) = \left\{f(X(i,j)) | \forall X(i,j) \in X\right\} \tag{4}$$

where (i, j) are the spatial coordinates of the pixel in the image [25].

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