Contrast Enhancement for X-ray Images Based on Combined Enhancement of Scaling and Wavelet Coefficients

Chun-Joo Park*, Do-II Kim*, Do-Yoon Jang*, Han Been Yoon1, Be-Young Choe*, Ho Kyung Kim1, Hyeong-Koo Lee*

*Department of Biomedical Engineering, College of Medicine, The Catholic University of Korea, Seoul,
1School of Mechanical Engineering, Pusan National University, Busan, Korea

An applied technique of contrast enhancement for X-ray image is proposed which is based on combined enhancement of scalings and wavelet coefficients in discrete wavelet transform space. Conventional contrast enhancement methods such as contrast limited adaptive histogram equalization (CLAHE), multi-scale image contrast amplification (MUSICA) and gamma correction were applied on scaling coefficients to enhance the contrast of an original. In order to enhance the detail as well as reduce the blurring caused by up scaling of contrast modified scale coefficients from lower resolution, the sigmoid manipulation function was used to manipulate wavelet coefficients. The contrast detail mammography (CDMM) phantom was imaged and processed to measure the image line profile of results and contrast to noise ratio (CNR) comparatively. The proposed technique produced better results than direct application of various contrast enhancement methods on image itself. The proposed method can enhance contrast, and also suppress the amplification of noise components in a single process. It could be useful for various applications in medical, industrial and graphical images where contrast and detail are of importance.

Key Words: X-ray image enhancement, Wavelet transform, Contrast enhancement

INTRODUCTION

Optimized visual interpretation with contrast enhancement is of critical importance in diagnostic radiology. Conventionally, adaptive contrast limited histogram equalization (AHE); contrast limited adaptive histogram equalization (CLAHE) and multi-scale image contrast amplification (MUSICA) are most widely known techniques to perform contrast enhancement of diagnostic images. Recently, various techniques using enhancement function in wavelet transform space have been actively proposed. Most of previous methods based on wavelet transform are focused on the enhancement of wavelet coefficients. Since the wavelet coefficients contain high frequency components of an original image in its respective directions (horizontal, vertical, and diagonal), the manipulation on wavelet coefficients will provide enhancement of detail contrast (more related to sharpness). It is the scaling function which determines the contrast enhancement of an original. In the conventional methods to enhance contrast via wavelet transform, manipulation was done only upon wavelet coefficients which are related to more like sharpness and resolution. In this study, we propose an applied technique of contrast enhancement for X-ray images which is based on the simultaneous enhancement of scaling and wavelet coefficients in discrete wavelet transform space. The concept of the proposed method is that if two components of approximation (scaling) and detail (wavelet) coefficients are controlled in combination, the contrast as well as detail can be enhanced. Since scaling coefficients are low
passed signal components which contain less amount of noise from the higher resolution, the conventional contrast enhancement method applied on scaling coefficients would provide less amount of noise amplification than the direct application on the image. We applied various contrast enhancement algorithms on scaling coefficients: CLAHE, MUSICA and gamma correction, which were compared with the direct application on images. Comparative evaluations in terms of contrast and contrast-to-noise ratio (CNR) on contrast detail mammography phantom showed that the new technique would be useful in contrast enhancement of various diagnostic images. The proposed method is also flexible to various gray level images and applicable to other contrast enhancement algorithms.

MATERIAL AND METHODS

1. Discrete wavelet transform

The wavelet series expansion of function f(x) of one dimension into relative wavelet \( \psi(x) \) and scaling function \( \varphi(x) \) is defined as,

\[
f(x) = \sum_{i} c_i \psi_{i,j}(x) + \sum_{i} d_i \psi_{i,j}(x)
\]

where \( j_0 \) is an arbitrary starting scale, and \( c_i \) and \( d_i \) are referred to as the approximation or scaling coefficients and detail or wavelet coefficients respectively. Fig. 1 refers to single level decomposition of wavelet transform. For each higher scale \( j \geq j_0 \) in the second sum, a finer resolution is added to the approximation.

2. Enhancement on scaling coefficients

As stated above, the scaling coefficient can be considered as approximation function from higher resolution. It is a low pass filtered image which determines the total contrast of the original. The mathematical expression of the proposed method can be denoted as

\[
\text{Enhancement} = \sum_k g^{-1} \left[ g'(\psi_j), g'(\psi_j), g'(\psi_j), k(\psi_j) \right]
\]

where \( L \) is the number of levels in the transform, function \( g \) and \( k \) are sigmoid function and conventional enhancement techniques to enhance contrast, respectively.

Followings are methods used to enhance the contrast of scaling coefficients

1) Contrast limited adaptive histogram equalization (CLAHE): AHE is an excellent contrast enhancement method for both natural and medical and other initially non-visual images. It is an applied method of histogram equalization (HE) of which, an image is divided into \( m \) by \( m \) contextual regions. In AHE, an image is divided into sub-blocks of same size which do not overlap, and transformation functions are obtained by calculating the cumulative sum of histogram of each contextual region.

CLAHE is an additive method of AHE, where histogram is restricted up to clip limit. AHE produces excellent results in the signal component of an image, but noise in the image is also enhanced. This effect is severe when HE is performed in relatively homogenous contextual region. The clip limit restricts the concentrated region in the histogram and hence prevents the excessive amplification of contrast in intensity concentrated regions.

2) Multi-scale image contrast amplification (MUSICA): The MUSICA algorithm is a different method to enhance contrast by equalizing the detail components of an original image. Unlike histogram equalization, which reshapes the image histogram by direct grey value manipulation, the MUSICA algorithm applies to signal frequency variations. The basic algorithm is as follows

1. Decomposition of an original image into a Laplacian pyramid representing local detail at all scales.
2. Modification of pyramid values according to power function.
3. Apply the inverse of the decomposition operator to attain a contrast enhanced image.

The power function used for modification is as follows.

\[
y(x) = aM \frac{X}{X_c} \left( \frac{X_c}{M} \right)^p \quad \text{if} \quad |x| < X_c.
\]
\[ y(x) = a \frac{X^p}{|X|^q} \]

where,
\[-M < x < M, X, \leq M\]
and \( x \) represents coefficients of Laplacian pyramid of respective resolution level, \( M \) is the maximum coefficient value, \( a \) is the amplification factor and \( p \) is the degree of non-linearity. In order to limit the amplification of noise, threshold is used as the transition point between linear to power function.\(^6\)

3) Gamma correction: The gamma corrections have the basic form
\[ G(x,y) = c f(x,y)^\gamma \]
where \( c \) and \( \gamma \) are positive constants. The algorithm is perhaps the simplest way of showing the contrast enhancement, since it is based upon simple manipulation of look up table (LUT) of an original image. As it can be suggested from the above equation, \( \gamma > 1 \) would show wider range of bright part and \( \gamma < 1 \) would show wider range of dark part in the output gray level than its original. Thus, the gamma correction can be useful for the general-purpose of contrast enhancement.\(^5\)

3. Enhancement on wavelet coefficients

In order to enhance the detail contrast for image, wavelet coefficients were enhanced by applying sigmoid operator.\(^5\) In the wavelet transformed space as it is stated, there are four components in the transform space: horizontal, vertical, diagonal and a residual component represented by \( \Psi_i^H, \Psi_i^V, \Psi_i^D \) and 2, respectively where \( i \) is the transform level. The detail enhancement can be achieved by
\[ \text{Enhancement} = \sum_{i=1}^{L} [g(w_{i})(w_{i}) g(w_{i})] \delta \]
where \( L \) is the number of levels in the transform and \( g \) is a sigmoid enhancement function. The sigmoid function \( g \) can be defined as,
\[ g(y, x) = \left\{ \begin{array}{ll}
\frac{1}{1 + e^{-y}} & \text{for} \ y > 0 \\
1 & \text{for} \ y = 0 \\
0 & \text{for} \ y < 0
\end{array} \right. \]
where, \( y(x) = \frac{y(x)}{max} \), \( \text{Max} \) is the maximum of gray value of all pixels in \( \Psi_i^r(x, y) \), \( r = H, V, D \) and \( a, b, c \) are coefficients which can be set adaptively. The sigmoid function \( \text{sgn}(y) \) is defined by
\[ \text{sgn}(y) = \frac{1}{1 + e^{-y}} \]
which is continuous and monotonically increasing within the interval [-1, 1]. In order to prevent amplification of noise, threshold value \( T^r \) is used as the transition point between linear and sigmoid function similar to that in MUSICA algorithm.\(^6\)

4. Image acquisitions

In order to quantitatively analyze the proposed method, contrast detail mammography (CDMAM) phantom manufactured by Armius Medical System was imaged and processed to measure the level of contrast enhancement. Also, in addition, diagnostic image of hand and mammography were acquired with amorphous selenium digital radiography detector of energy 80 and 32 KeV respectively.

RESULTS

1. Contrast detail mammography (CDMAM) phantom Images

Fig. 2 shows an original and processed images processed by the proposed method of applying gamma correction, MUSICA and CLAHE to wavelet basis and sigmoid function to wavelet coefficients. From the result shown, on any of contrast enhancement algorithm used on wavelet basis along with coefficient stretching, can enhance the contrast of an original.

2. Comparative study

1) Image profiles: In order to compare the performance of the proposed method with other methods which are applied directly upon original images, the intensity profile of each processed image was acquired and analyzed. Fig. 3 refers to comparative line profile on the gold plate of same position in CDMAM phantom with the direct application of CLAHE and the proposed method from the original image. It has been measured in order to compare the local contrast variation which represents contrast as well as noise of the signal. Referring to the figure, the level of noise amplification by the contrast stretching is lower in the proposed method than the
Fig. 2. Comparison of images of original (a) and proposed method where gamma correction (b), MUSICA (c), CLAHE (d) were applied on the wavelet basis with sigmoid function applied on wavelet coefficients.

Fig. 3. Image Profile of CLAHE applied directly upon original image (a) and CLAHE applied on wavelet basis with sigmoid enhancement on wavelet coefficient (b).

direct application on the original image. As stated above, the amplification of noise component was suppressed by assigning the transition point from linear to sigmoid function when wavelet coefficient was enhanced. This result suggests that the proposed method can enhance the contrast as well as suppress the amplification of noise which takes place on direct application of the contrast enhancement algorithms.

2) Comparative measure on contrast to noise ratio (CNR): CNR refers to the ability of an image to distinguish between contrasts of acquired image and the inherent noise in the image. It is defined

\[
\text{CNR} = \frac{S_a - S_b}{\sqrt{\sigma_a^2 + \sigma_b^2}}
\]  

where, \( S_a \) and \( S_b \) are signal intensities for region a and b.
Fig. 4. Comparative measure of contrast to noise ratio between original, directly applied and proposed method of CLAHE (a), MUSICA (b), and Gamma Correction (c).

$\sqrt{\sigma_a^2 + \sigma_b^2}$ refers to the noise, which is usually measured from the region a and b, i.e., the measured standard deviation of the region a and b. Fig. 4 shows the measured CNRs of CDMAM phantom images of various gold disk thicknesses where original, direct and proposed methods which were acquired as shown in Fig. 2 were compared. From the result shown in the figures, application of the conventional contrast enhancement methods on the wavelet basis and sigmoid enhancement function on wavelet coefficients is better than the direct application on original image in terms of CNR.

3. Applications

Fig. 5 shows the magnified view of finger joints. Compared with the direct application of CLAHE, sharpness is further enhanced in the proposed method. The proposed method was also applied to mammographic images and result was compared with the previous contrast enhancement using wavelet transform (Fig. 6). Referring to the figure, the proposed method has shown better in terms of image quality than the previous method of contrast enhancement using wavelet transform.

DISCUSSION

Contrast as well as detail of an image could be enhanced by applying conventional contrast enhancement method and sigmoid magnitude stretching function on wavelet basis and coefficients respectively. The method is better than the direct application of conventional method in terms of CNR as well as the interpretatio of its detail.

Maximum decomposition level for applying proposed method was two in the case of 1024×1024 sized 12 bit images. Manipulation from further level would cause artefacts due to Gibbs phenomena. Applying the proposed method from one decomposition level was good enough to express the contrast enhancement as well as detail. Since the contrast enhancement algorithm is being applied on the low pass filtered residual (wavelet basis), the manipulation on wavelet basis without applying magnitude stretching function (sigmoid function) on coefficients would cause blurring on edges. The amount of stretching should be set adaptively according to the characteristic of the image. In the case of images where gray level in-
CONCLUSION

The contrast enhancement as well as the detail enhancement of an image could be simultaneously achieved by enhancing wavelet basis and wavelet coefficients at the same time. Since wavelet basis is low pass filtered components, applying the contrast enhancement algorithm on the wavelet caused a less amount of noise amplification than the direct application to an original image. Since wavelet coefficients contain high pass filtered components, applying the sigmoid function to stretch the magnitude of coefficients would result in detail enhancement. The method is flexible, and thus be applicable to various fields especially in radiology, where contrast as well as detail is of importance.

REFERENCES

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웨이브렐트과 기저 계수를 이용한 X-ray 영상의 대조도 향상기법

*가톨릭대학교 의과대학 의공학과, †부산대학교 기계공학부
바경주*, 김도일*, 정도운*, 윤한빈†, 최보영*, 김호경†, 이효구*

본 연구에서는 이신 웨이브렐트 도메인에서 기저계수와 웨이브렐트 계수의 변환을 이용하여 X-ray 이미지의 대조도 향상을 시키는 방법을 제안하였다. 기저 계수의 변화는 기존에 사용되는 contrast limited adaptive histogram equalization (CLAHE)와 multi-scale image contrast amplification (MUSICA)와 같은 보편적인 영상의 대조도 향상 기법을 적용하였으며 대조도 향상은 자세한 자세화도 기저 계수의 변환으로 인한 Blurring 환상을 방지하고 또한 이미지의 선명도를 향상시기 위하여 웨이브렐트 계수에 sigmoid function을 적용하였다. 본 알고리즘에 대한 성능 평가를 위하여 contrast detail mammography (CDMAM) 텐텐의 영상을 토대로 기존에 사용한 대조도 향상 기법들과 contrast to noise ratio (CNR) 및 line profile에 대한 비교평점을 실시하였고 그 결과 기존의 대조도 향상기법과 웨이브렐트 도메인에서 적용하는 것이 뛰어난다는 것을 알 수 있었다. 본 영상 대조도 향상기법은 영상의 대조도를 증가시키는 동시에 잡음의 증폭을 효과적으로 억제할 수 있다. 따라서 본 연구는 의료 영상뿐만 아닌 대조도 향상도 기술로서는 여러 분야에 적용될 수 있으리라 기대한다.

중심단어: X-ray 영상 향상 기법, 웨이브렐트 변환, 대조도 향상 기법