

IMPROVEMENT OF IMAGE QUALITY AND RADIATION DOSE REDUCTION IN DIGITAL RADIOGRAPHY USING AN INTEGRATED WAVELET- TRANSFORM-BASED METHOD

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Abstract: This study presents an improved wavelet-transform-based method for offering a possibility to reduce the radiation dose while maintaining a clinically acceptable image quality. The proposed method integrates a straightforward extension of our previously proposed wavelet-coefficient weighted method and the existing BayesShrink thresholding method. Experimental results demonstrated that the proposed method could improve the resolution characteristic while keeping the noise level within an acceptable limit. Our visual evaluation also showed that an approximately 40% reduction in exposure dose could be achieved with the proposed method in hip joint and lumbar spine radiographs.

Keywords: Wavelet transforms, Radiation dose, Image quality, Noise reduction, Image processing

1. INTRODUCTION

The introduction of digital radiography has improved image quality and allowed for further reduction of patient exposure. However, digital radiography also poses risks, such as unnoticed increases in patient dose. The issue of radiation dose exposure to the patients with digital radiography is a major public health concern. In particular, it is important to keep the radiation dose exposure to a minimum for patients in their reproductive period, who frequently undergo repeated radiation exposure during the course of diagnostic imaging and treatment follow-up.

It is known that a trade-off exists between noise level and radiation dose. On the one hand, high-dose radiation will lower the noise level, but may give excess radiation doses to the patient. On the other hand, low-dose radiation will lower the signal-to-noise ratio of the image and result in reducing the amount of image information. The balancing of dose and image quality should be performed explicitly to ensure that patient doses are kept as low as reasonable achievable, while maintaining a clinically acceptable image quality. To deal with this issue, much research, such as the development of new detectors and that of image processing methods has been carried out. In recent years, several

investigators have reported that wavelet-based image processing techniques are effective in the reduction of radiation dose [1, 2].

One of the most widespread uses of the conventional radiography is for the pelvis and lumbar spine. However, the radiation dose for pelvic and lumbar x-ray examinations using radiograph is relatively high if an acceptable image quality is to be obtained. An effort to reduce the exposure dose can have a positive effect on a patient's quality of life.

In this work, we propose an improved wavelet-transform-based method for offering the possibility to reduce the radiation dose while maintaining a clinically acceptable image quality. The proposed method integrates the advantages of our previously proposed wavelet-coefficient-weighted method and the existing BayesShrink thresholding method [3-5]. To verify the effectiveness of the proposed method, we measured and compared the presampled modulation transfer functions and the noise power spectra of the processed computed radiography images. Visual evaluations were also performed by five experienced radiological technologists.

2. MATERIALS AND METHODS

2.1 Proposed method

The main steps of the proposed method include a previously reported wavelet-coefficient adjustment technique for contrast enhancement [4, 5] and a wavelet thresholding technique for noise reduction [2, 3]. Figure 1 shows a schematic diagram of the proposed method. As shown in Fig. 1, the proposed method for denoising radiographic images starts by decomposition of the original image by use of the discrete wavelet transform, which results in obtaining different detail wavelet coefficients (horizontal, vertical, diagonal). The three detail coefficients are then processed by use of a sigmoid-type transfer curve for adjustment of wavelet coefficient, followed by BayesShrink thresholding.

Sigmoid-type transfer curve for wavelet coefficient weighting adjustment

The sigmoid filter is used to enhance image contrast: the coefficients with great values and the coefficients of high resolution levels are heavily weighted. In the wavelet decomposition of level j , the sigmoid-type transfer curves of wavelet coefficient can be expressed as follows:

$$w_{output}^j(m, n) = a \times \frac{1}{1 + 1/\exp\left[\frac{w_{input}^j(m, n) - c}{b}\right]} \times w_{input}^j(m, n) \quad [\%], \quad (1)$$

where $w_{input}^j(m, n)$ and $w_{output}^j(m, n)$ represent input and output values, respectively. In this study, the value of a was computed using equation (2):

$$a = 2 - \frac{(j-1)}{N}, \quad (2)$$

where N represents the maximum decomposition level. Consequently, if decomposition j becomes smaller, the gradient of the graph obtained from equation (1) get greater. The constant c was determined using equation (3).

$$c = d + b \times \ln(a - 1.0), \quad (3)$$

where, d is a constant used to determine inflection point of sigmoid curve. b represents a constant to determine gradient of sigmoid curve. The values of d and b used in this study are 25 and 20, respectively. With regard to d , 25 % and below noise were controlled [5].

BayesShrink thresholding technique

In the BayesShrink scheme, the threshold is determined for each subband by assuming a generalized Gaussian distribution (GGD) [2, 3]. The BayesShrink threshold, T_B , is given as

$$T_B = \frac{\sigma^2}{\sigma_x}, \quad (4)$$

where σ^2 is the noise variance and σ_x the signal standard deviation. Because the noise is independent and identically distributed, the estimated variance of the observed image, σ_y^2 , can be written as

$$\sigma_y^2 = \sigma_x^2 + \sigma^2. \quad (5)$$

The estimated variance of signal σ_x^2 is then deduced by

$$\sigma_x = \sqrt{\max(\sigma_y^2 - \sigma^2, 0)}. \quad (6)$$

A robust estimator of the noise variance is obtained by

$$\sigma = \frac{M}{0.6745}, \quad (7)$$

where M is the mean value of the absolute wavelet coefficients in the first decomposition level. A detailed explanation of the BayesShrink method is given in ref [2, 3].

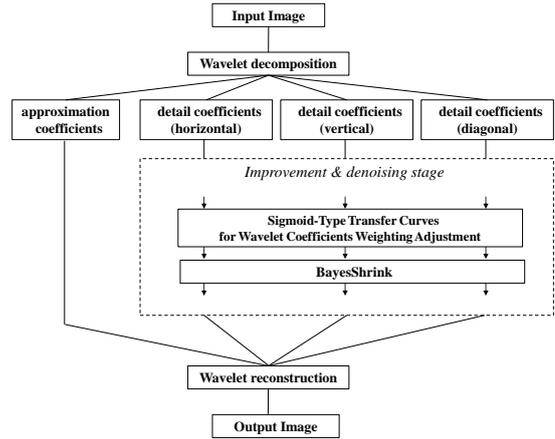


Fig.1 Flow chart of the proposed method.

2.2 Data acquisition

Images that were used for measurement of physical characteristics were acquired with a computed radiography (CR) system (FCR XG-1, Fuji Photo Film, Tokyo, Japan) and an imaging plate (ST-V_N, Fuji Photo Film, Tokyo, Japan) in the study. A pixel size of 0.1 mm and a quantization level of 10 bits were employed for data acquisition. Images were taken with a radiation quality of RQA-5 (HVL=7.1 mm Al, 21 mm Al additional filtration). The amount of exposure was 4.63×10^{-7} C/kg (50 mAs). Twenty phantom images were obtained and used for measuring the presampled modulation transfer function (MTF), noise power spectrum (NPS), and gray level contrast (GLC).

A visual evaluation of wavelet-processed images of a human body phantom was performed to confirm the effectiveness of the proposed method for reduction of the radiation dose. An anterior-posterior (AP) projection of the hip joint and the lateral view of the lumbar spine on the human body phantom were exposed at various dose levels. These two images were also taken with four different radiation levels, 50/100, 64/100, 80/100, and 100/100, as compared to the reference level that is commonly used in clinical radiology practice. In this study, the hip joint phantom was exposed at 70 kVp and 32 mAs, and the lumbar phantom at 82 kV, 64 mAs.

2.3 Measurement of physical characteristics

MTF

The presampled MTFs were measured with an angled-edge method. The edge device is made of a 1-mm-thick sharp-edged-tungsten plate. The edge spread function (ESF) in the direction perpendicular to the edge was then obtained. Then differentiated the ESFs to obtain the line spread functions, and the presampled MTFs were deduced by Fourier transformation.

NPS measurements were made by exposure of the imaging plate to a uniform beam of radiation. For determination of the NPS, a two-dimensional 2nd-order polynomial was fitted and subtracted to remove background trends. For the calculation, the central portion of each uniform image obtained was divided into 4 non-overlapping regions, 256×256 in size. The NPS was calculated by applying the fast Fourier transform and then averaging the resulting spectrum estimates.

GLC

A commercially available Burger phantom (Kyoto Kagaku, Kyoto, Japan) was employed for measurement of GLC characteristics. In this study, the GLC was used to describe the relative contrast of the image, defined by

$$C_L = \frac{L_{acrylic} - L_{BG} + 1}{L_D}, \quad (8)$$

where, $L_{acrylic}$, L_{BG} , and L_D represent the mean pixel values of the acrylic disk, that of the background, and gray level of the CR, respectively.

2.4 Performance comparison

In order to validate the superiority and effectiveness of the proposed method, we compared the proposed method with 3 conventional methods, namely, the Wiener filter (WF), BayesShrink method, and sigmoid-type method. In the wavelet-transform-based method, wavelet basis functions of Daubechies (order = 4, level = 4) were adopted for image processing. The proposed method and the above-described three methods were applied to the original images for performance comparison.

2.5 Visual evaluations

A visual evaluation was conducted by five experienced radiological technologists. The images were displayed on a liquid-crystal display (1280×1024 matrix, LCD-1980SX_i, Nippon Electric Company, Tokyo, Japan). The parameters of window level, window width, and display image size on the image display apparatus were fixed. The five radiological technologists independently evaluated the total depiction of each phantom image for diagnostic acceptability. Pairwise comparisons were performed with Scheffe's method at each dose ratio. Comparisons were made by use of five possible combinations, that is, WF-processed image, BayesShrink-processed image, sigmoid-processed image, proposed filter-processed image, and the original image.

3. RESULTS

Figure 2 shows the MTFs for the original image and the four processed images. The MTF for the sigmoid shows the highest, followed by that for the proposed method. Both the MTFs are considerably superior to the original image over the entire spatial frequency range. In contrast, the MTFs obtained from the BayesShrink and the WF methods are slightly lower than the original one.

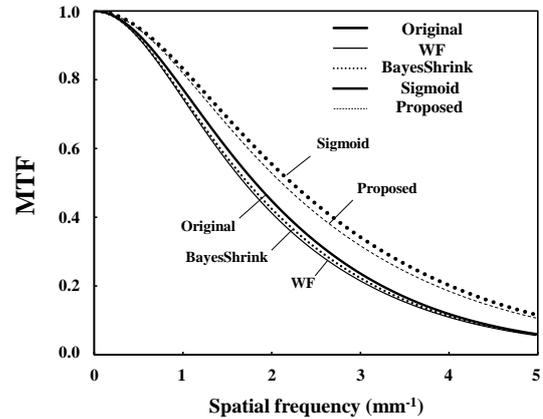


Fig. 2 MTFs for the original image and the four processed images.

Figure 3 shows the NPS values. The NPS values for the sigmoid method had a pronounced increase as compared to that of the original image. The NPSs values for the proposed method are slightly higher and similar to those of the original image. In contrast, the NPS values for the BayesShrink and WF methods decreased as compared to those for the original images.

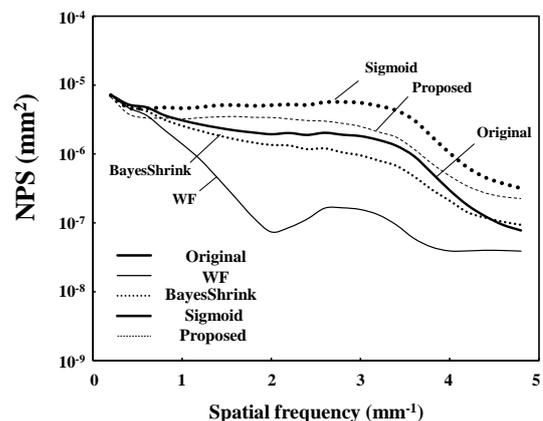


Fig. 3 NPSs for the original image and the four processed images.

Figure 4 shows the GLC as a function of the radiation dose ratio. The sigmoid and the proposed methods could considerably improve the GLC at a 64/100 radiation dose ratio with respect to the standard dose, although the value of the GLC with the sigmoid and proposed methods is slightly lower than the original image at 100/100 and 80/100 radiation dose level. Furthermore, the proposed method shows the highest performance among all images at the 50/100 radiation dose ratio.

4. DISCUSSION AND CONCLUSIONS

Our proposed method provides benefits in improving the resolution and suppressing noise. The experimental results demonstrate the effectiveness of dose reduction without degradations of image quality at a lower dose as compared to the standard dose. In the MTF and NPS measurements (Figs. 2 and 3), the physical properties of the images processed by use of the sigmoid-function and BayesShrink methods show distinct differences. The sigmoid function yields improved spatial resolution characteristics with increasing noise. In contrast, the BayesShrink method gives improved noise, but deteriorating spatial resolution. The proposed method incorporates the sigmoid method into the BayesShrink algorithm. As a result, the proposed method shows better spatial resolution and noise properties as compared to the original image. Furthermore, the image contrast can be improved as compared to that of the original image at relatively lower dose ratios (Fig. 4). Image contrast is one of the most important factors affecting the detectability of detailed features, such as the trabecula of bone.

The results of our study indicate that the proposed strategy significantly improves the quality of low-dose images such that CR images obtained at 50% and 64% of the standard dose level provide clear depiction in AP views of the hip joint and in lateral views of the lumbar spine, respectively, in term of visual evaluation, as shown in Fig. 5. The visibility of the overall appearance of bone is improved by the proposed method. This may be due to the improvement of contrast and resolution and the suppression of noise. Maintaining a well-balanced relationship among contrast, spatial resolution, and noise is important. The proposed method has a well-balanced filter at lower dose.

In summary, the experimental results demonstrated that the proposed method could improve the resolution and contrast characteristics while keeping the noise level within acceptable limits. Furthermore, our visual evaluation showed that an approximately 40 - 50% reduction in the exposure dose might be achieved with the proposed method. The proposed method has the potential to improve visibility in radiographs when a lower radiation dose is applied.

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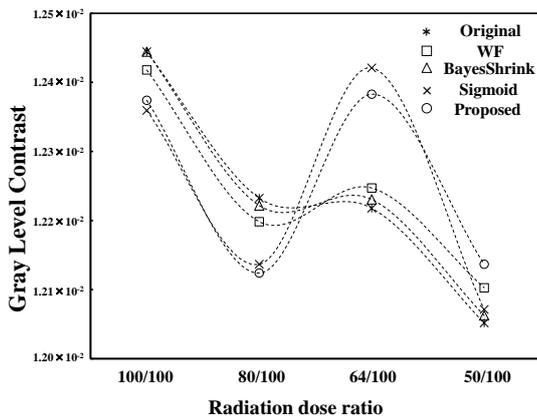


Fig. 4 Gray-level contrasts as a function of the dose ratio for the original image and the four processed images obtained using a Burger phantom.

Figure 5 illustrates visual evaluation results for the hip joint and lumbar spine at various radiation dose ratios by use of Scheffe's method. In terms of diagnostic acceptability, the proposed method provides significantly better results compared to those for the original image up to a 64/100 radiation dose ratio in the hip joint. When the radiation dose ratio was 50/100, no significant difference was found between the image processed by the proposed method and the original image. In the lumbar radiographs, the result obtained from the proposed method was comparable to the original image up to a 64/100 radiation dose rate.

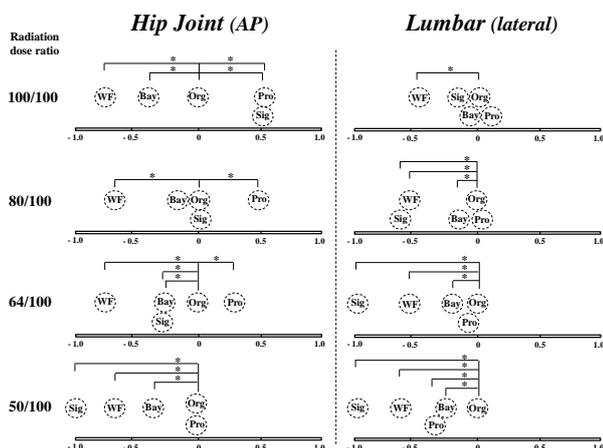


Fig. 5 Visual evaluation results using Scheffe's method of paired comparisons of the original image (Org) and various images processed by the WF, BayesShrink (Bay), sigmoid (Sig), and the proposed (Pro) methods at each radiation dose ratio with respect to the standard dose. There was a significant difference ($p < 0.01$) between the original and the processed image at various dose ratios if the * mark is shown.