Unsharp Masking Technique Using Multiresolution Analysis for Computed Radiography Image Enhancement

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An unsharp masking technique (USM) is one of the image processing methods used in the computed radiography (CR) system. To further promote the performance of the USM, we developed the NEW-USM processing that can control the frequency enhancement characteristics flexibly and accommodate an extensive range of diagnostic targets. The NEW-USM and USM were performed on femur images acquired by computed radiography (model FCR9000; Fuji Medical Systems USA Inc, Stamford, CT), and the resulting images were compared. In the NEW-USM image, bone structures are enhanced as sharply as in the USM image, whereas the surrounding soft tissue structures, such as muscle are enhanced more strongly than in the USM image. Furthermore, the absence of the bone structure that may suggest pathological change is more obvious in the NEW-USM image. The newly developed NEW-USM can appropriately enhance diagnostic information over the whole range of image frequencies, thereby expanding utility of the USM.

KEY WORDS: computed radiography (CR), image enhancement, unsharp masking technique (USM), multi resolution analysis, spatial frequency response.

A COMPUTED RADIOGRAPHY (CR) system reads digital x-ray information from an imaging plate, converts it to image information suitable for diagnosis through digital image processing, and eventually images it on a silver-halide film or CRT display.[1,2] An unsharp masking technique (USM) is one of the various types of image processing employed in the CR system.

USM, which is expressed in the following equations, enhances the difference between a pixel of interest and a mean value of its local neighborhood, depending on the density of the pixel of interest:

$$\text{Sproc} = \text{Sorg} + \beta(\text{Sorg}) \times \text{Shigh} \ldots \quad (1)$$

$$\text{Shigh} = \text{Sorg} - \sum_{i,j=0}^{N} S_{i,j}/(N \times N) \ldots \quad (2)$$

where Sorg, Shigh, Sus, and Sproc stand for an original image, a higher spatial frequency image, an unsharp image, and a USM image, respectively; and β denotes a coefficient for controlling the degree of enhancement.

The frequency element contained in the image that is most enhanced is determined by the mask size, N. That is, the larger the mask size, the more enhanced is the low-frequency side, while the smaller the mask size, the more enhanced is the higher-frequency side. The enhancement coefficient β(Sorg) is a function of Sorg, such that the coefficient β is generally small with small Sorg (low exposure region), while it becomes greater with greater Sorg (high exposure region). This minimizes the noise in the low exposure region, which contains much quantization noise.

The Fuji Computed Radiography (FCR) system can control the USM characteristics according to three parameters, ie, spatial frequency rank (RN: related to the mask size), enhancement coefficient (RE: related to β), and density-dependent type (RT: related to β). The FCR system sets its image processing parameters optimized for each anatomical region or diagnostic target.

The present report describes a new USM algorithm (hereinafter referred to as NEW-USM) we developed, which employs multiresolution analysis in USM processing to further extend the capability of the USM to permit more flexible control of image enhancement.

NEW-USM ALGORITHM

When USM was first developed, the microprocessor had only limited computing capacity and memory devices were prohibitively priced. However, recent years have seen rapid advances in computer technology, resulting in dramatic improvement in processing capability and lower memory prices. As such, it is now possible that more complex image processing algorithms can be processed quickly.

To further promote the performance of the USM, we examined USM processing that can control the

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frequency enhancement flexibly and accounts for an extensive range of diagnostic targets.

The features of the NEW-USM are twofold: on the one hand, unlike USM, which computes enhancement components with a single unsharp image, the degree of enhancement or enhancement coefficient, can be controlled for each frequency band by using a plurality of unsharp images having different frequency characteristics; and, on the other hand, by nonlinearly converting the image signal for each spatial frequency band, excessive enhancement is prevented.

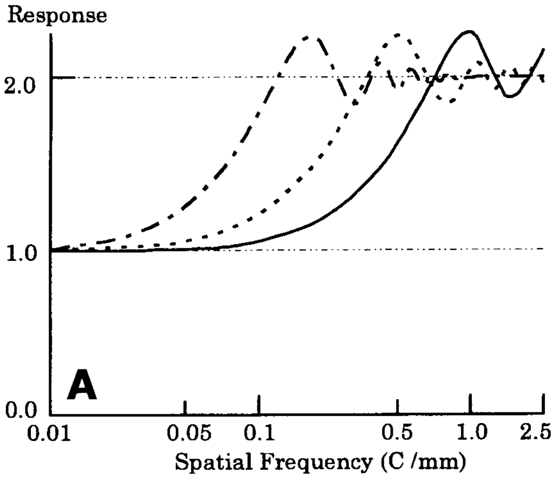
The NEW-USM algorithm can be expressed in equations (3) and (4). Equation (3) is identical to that for the USM, where RT and RE, which are parameters related to β (Sorg), are equivalent to those used in the USM.

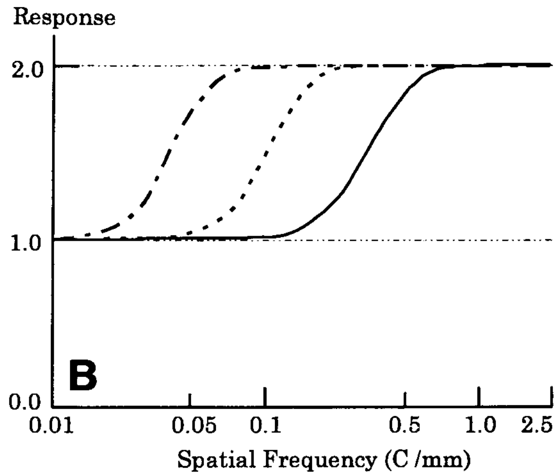
A difference between USM and NEW-USM may be found in how a higher spatial frequency image (Shigh) is prepared, as shown in equation (4):

$$\text{Sproc} = \text{Sorg} + \beta(\text{Sorg}) \times \text{Shing} \ldots \quad (3)$$

$$\text{Shigh} = \sum_{m=1}^{M} f_m(\text{Sus}_{m-1} - \text{Sus}_m), \quad \text{Sus}_0 = \text{Sorg} \ldots \quad (4)$$

Sus_1, Sus_2, . . . , Sus_M, which are unsharp images having different frequency characteristics, are obtained by interpolating images on each hierarchical level of the image structure, called a Gaussian Pyramid[3] derived from the original image (Sorg) into the size of the original image through use of third-order B-spline interpolation.[4,5] The smaller the value of m, the unsharp image contains information with higher spatial frequency bands. A differential image between neighboring unsharp images





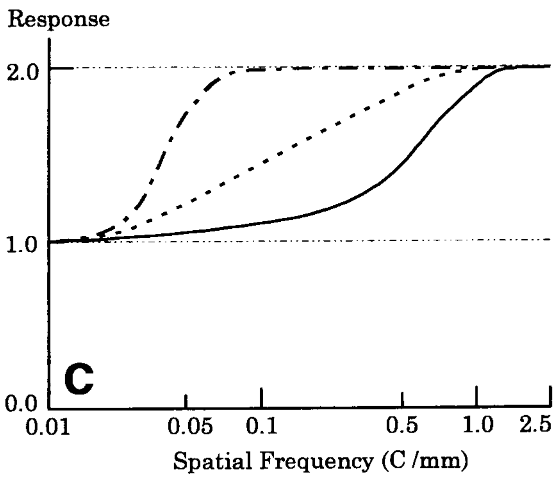


Fig 1. (A) Spatial frequency response of USM. (B) Spatial frequency response of NEW-USM (1). (C) Spatial frequency response of NEW-USM (2).

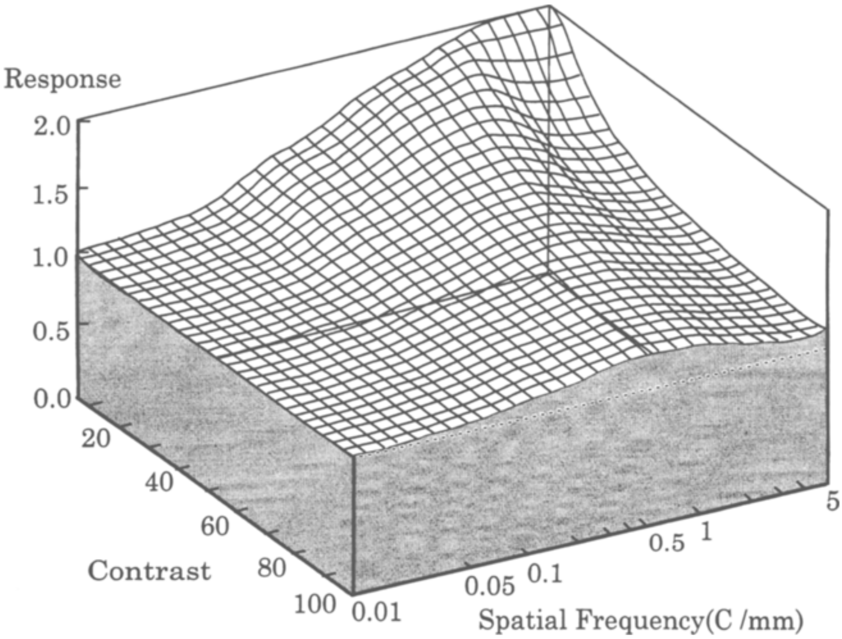


Fig 2. Contrast-adaptive spatial frequency response of NEW-USM.

$(Sus_{m-1} - Sus_m)$ represents a bandpass image in a certain frequency band. f_m denotes an M number of nonlinear functions, which is defined by the following equation:

$$Sout = Sin \times (\exp(X_m/Sin) - 1) / (\exp(X_m/Sin) + 1) \times Y_m \tag{5}$$

where:

Sin = input signal;

Sout = output signal;

X_m: suppression parameter;

Y_m: enhancement parameter ($0 \leqq Y_m \leqq 1.00$).

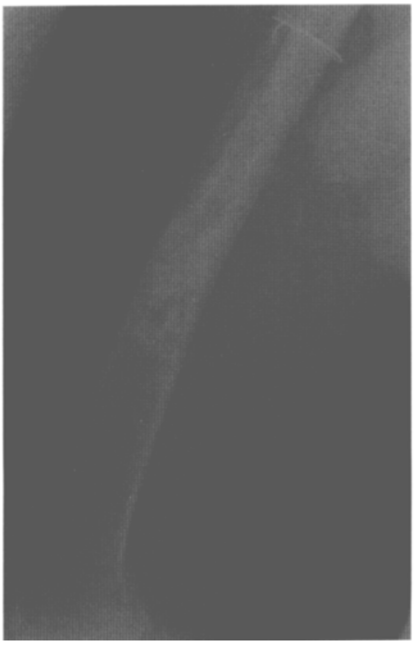


Fig 3. Original image.

Fig 4. USM image.

This nonlinear function has linearity when the input signal has a sufficiently smaller value than that of X_m; however, when the input signal assumes a value greater than X_m, it has nonlinearity such that the output signal approaches $X_m/2$ asymptotically when $Y_m = 1.0$.

The spatial frequency responses of the USM and NEW-USM are shown in Fig 1. With the USM, the frequency band that is most enhanced can be controlled by setting the frequency rank (RN) (as shown in Fig 1A). With the NEW-USM, on the other hand, by controlling the enhancement coefficient Y_m for each bandpass image, it is possible to create enhanced images having any frequency response, such as those similar to USM (as shown in Fig 1B) and those with gradually increasing enhancement from low to high spatial frequencies (as shown in Fig 1C). Furthermore, to suppress excessive enhancement of high-contrast information, the NEW-USM performs nonlinear conversion of bandpass images and then sums them together to calculate a enhancement signal, so that it exhibits a contrast-adaptive spatial frequency response, as shown in Fig 2.

RESULTS AND DISCUSSION

The NEW-USM and USM were performed on thigh images acquired by the FCR9000 (sampling pitch of 200 μm/pixel), and the resulting images were compared. Figures 3 and 4 show an original image and a USM image, respectively. The image processing parameters for the USM were RN: 5 (mask size of 15 by 15 pixels), RT: T, and RE: 5.0, which are generally used to image thighs. These parameters are intended to enhance higher spatial frequency information, such that the bone structure is extracted sharply, as can be seen when compared with the original image (Fig 3).

A NEW-USM image is shown in Fig 5. Its image processing parameters are RT: T and RE: 7.0; the enhancement at 0.5 C/mm, ie, a main frequency component of the bone structure, was identical to that of the USM. The nonlinear function parameters were $X_1 = X_2 = X_3 = X_4 = X_5 = 20$, $Y_1 = 1.00$, $Y_2 = 0.81$, $Y_3 = 0.66$, $Y_4 = 0.42$, and $Y_5 = 0.29$.

Figure 5, when compared with Fig 4, indicates that the bone structure is extracted sharply as in the USM image, while at the same time the soft tissue structure, such as muscles, is also enhanced, so it is easier to diagnose. Furthermore, apparent omissions of the bone structure that may suggest a pathological change are more obvious in Fig 5.

Fig 5. NEW-USM image.

Figure 6 shows spatial frequency responses of the USM and NEW-USM employed. The USM has an enhancement characteristic with a peak at 0.5 C/mm, whereas the NEW-USM has an characteristic with gradually increasing enhancements, ranging from 0.01 C/mm to 2.5 C/mm.

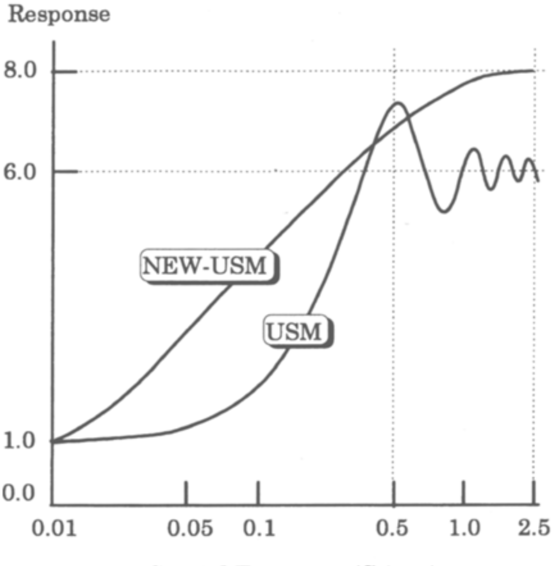


Fig 6. Spatial frequency responses of USM and NEW-USM.

It is considered that the NEW-USM can promote the ability to image not only the bone structure, but also the soft tissue structure by enhancing the low frequency components, as well as the high frequency portions.

It should be noted that there is a shadow of a wire in the upper portion of the image; artifacts observed near the wire in the USM image are absent in the NEW-USM image. This may be explained by the fact that a high-contrast signal is not enhanced excessively by the nonlinear function.

CONCLUSION

The current USM is a good image processing technique capable of enhancing image information quickly, ranging from low to high frequencies. It has been employed for more than 10 years in the CR system as one of its basic image processing schemes. The newly developed NEW-USM can appropriately enhance the diagnostic information over the whole range of image frequencies, thereby expanding the latitude in enhancement characteristics of the USM.

We expect that this new technology will further promote the diagnostic quality of the CR image.

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