Improvement of Diagnostic Image Quality Using a Frequency Processing Based on Decomposition into Multiresolution Space -Hybrid Processing-

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1. Introduction

CR (Computed Radiography) conventionally uses techniques such as Automatic Gradation processing, Frequency Enhancement processing, and qualization processing to convert digital X-ray images into a form suitable for diagnosis.

Automatic Gradation processing employs a uniform-increase function f(x) to convert the pixel values of image data. For CR imaging, the function f(x) is often an S curve approximating film gradation characteristics.

Although the gradation characteristics of the CR image usually have a linear relation to the of X-ray dose, this kind of conversion makes it possible to approximate the gradation characteristics of images produced with conventional system. By varying the function f(x), various gradation characteristics can be achieved.

On the other hand, Frequency Enhancement processing and Equalization processing are based on a frequency analysis of the image. Frequency Enhancement processing divides the image data into high-frequency and low-frequency components, in order to control image sharpness by adjusting response in the high-frequency range. For Equalization processing, density compensation components are calculated based the low-frequency range. These components are then added to the original image, in order to bring all areas of the image within the visible density range, but without altering the high-frequency response.

The above mentioned frequency processing techniques are useful for improving diagnostic image quality, but drawbacks such as increased noise and artifacts caused by the processing stage do exist. Various attempts are being made to solve such problems. The rapid spread of monitor-based diagnosis, as well as drastic advances in hardware speed have made the development of flexible and sophisticated image processing techniques with the capability for interactive adjustment more desirable than before.

2. Processing Algorithms

2.1 Decomposition into Multiresolution Space

In the fields of function analysis in general and wavelet analysis in particular, as well as for signal processing applications, intensive research is being carried out using a method called multiresolution analysis (MRA) of hierarchical function space strings.

Hybrid processing (hereafter called H processing) is a new frequency processing technique destined to supersede conventional frequency processing. It encompasses two distinct approaches, namely H-F processing for Frequency Enhancement processing, and H-E processing for Equalization processing. The algorithms for H-F processing and H-E processing are shown in Figure 1 and Figure 2, respectively. For both methods, the original image is decomposed into multiple hierarchical unsharped images for extracting distinct frequency components. This process is referred to as decomposition into a multiresolution space, a term derived from signal processing terminology. The process encompasses the steps listed below:

(1) Create multiple unsharped images from original image.

(2) Apply compensation processing (described below) to unsharped image to convert it into density dependent unsharped image.

(3)Extract distinct frequency band components by calculating differential of adjacent ranges.

For H-F processing, the extracted differential images are added to the original image, resulting in an enhanced image. For H-E processing, the added high-frequency components are subtracted from the original image, and the resulting low-frequency components are used to calculate the density compensation values.

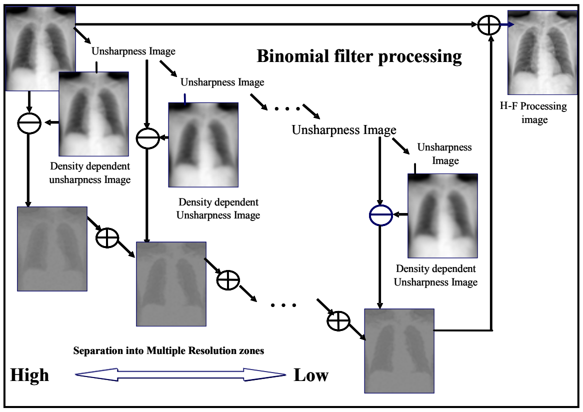


Fig.1 H-F processing Algorithm

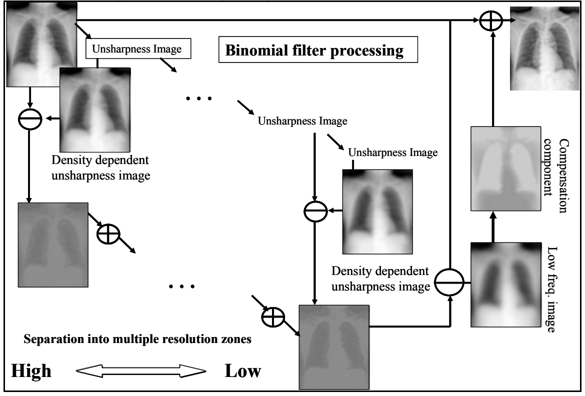


Fig. 2 H-E processing Algorithm

The frequency response of the differential images obtained by this decomposition process is shown by the dotted lines in Figure 4. By adjusting the way in which these components are summed, the enhanced frequency area can be controlled. The three solid lines in the graph named HF-STANDARD 1, 3, 6 are examples for preset emphasis curves created by H processing. Lower numbers indicate stronger low-frequency content.

Figure 5 shows a part of a frontal thorax image (lower left part of lung) obtained with HF-STANDARD 3 processing. As opposed to conventional frequency processing (Figure 3) where only a specific frequency band is enhanced very strongly, H processing yields natural enhancement that is independent of the size of the structural part. This is due to a frequency response curve that rises smoothly from the low frequency band to the high frequency band.

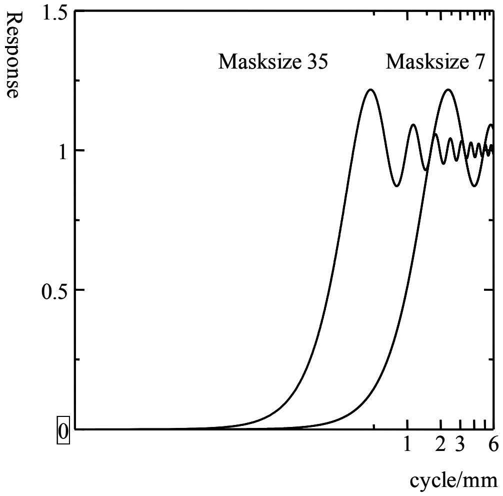


Fig.3 Frequency response (Conventional)

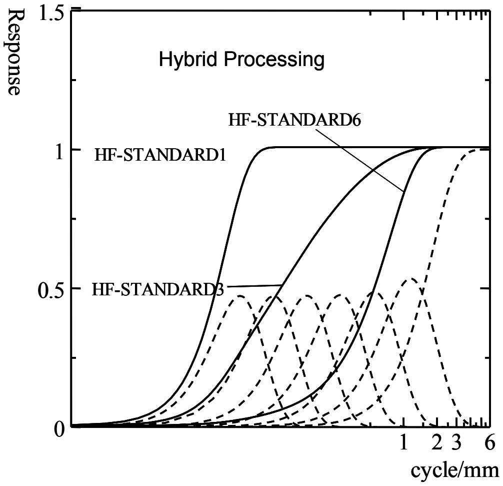
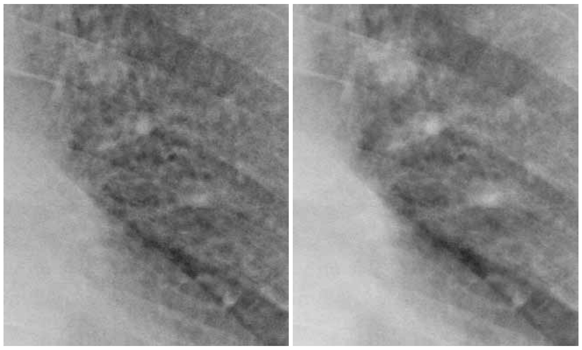


Fig.4 Frequency response (Hybrid)



Conventional Hybrid

Fig. 5 Example for thorax image processing

2.2 Binomial Filter

To create the unsharped images, a new type of filter processing called binomial filter averaging is employed.

A simple averaging filter with mask size 2 is applied in multiple iterations. This filter makes use of the fact that the binomial distribution B(n,1/2) converges towards Gaussian distribution for higher values of n. By changing the number of filter iterations, various Gaussian weighting characteristics can be achieved, with results that are equal to a filter using Gaussian weighting. Because the method involves only repeated simple averaging, high processing speed can be achieved.

The frequency responses of unsharped images created by simple averaging filter processing and binomial filter processing are shown in Figure 6. The smooth frequency response obtained with the binomial filter has the advantages described below.

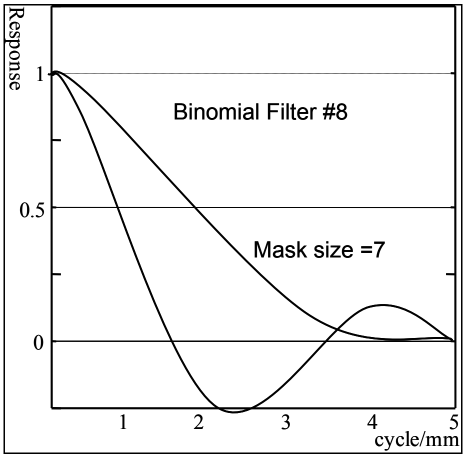


Fig.6 Unsharped image frequency response

Figure 7 illustrates simple averaging filter processing and binomial filter processing of a step image, resulting in two different enhanced images. Compared to the simple averaging image, edge enhancement with the binomial filter is notably smoother. This demonstrates that H processing enhances produces less overshoot and undershoot than comparable enhancement with conventional processing, allowing all parts of the image to be used for diagnosis.

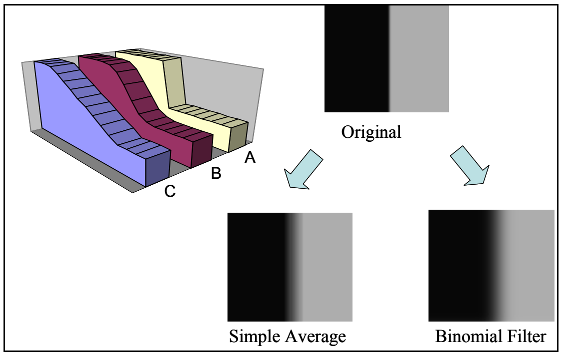


Fig.7 Example for step image processing

2.3 Density Dependent Image Unsharping

A density dependent unsharped image is created by adding compensation components to the blurred image. As shown in Figure 8, the compensation value is calculated from two elements, namely the signal value (density value) and the contrast of the blurred image. For Figure 8, the following applies: the higher the contrast or the lower the image signal value (density), the larger the compensation value.

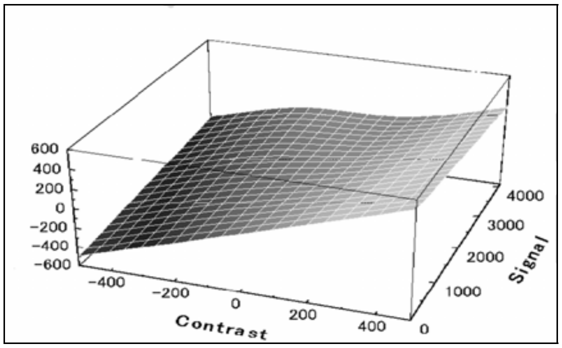


Fig. 8 Unsharped image compensation function

Density dependent image unsharping as used in H-F processing and H-E processing offers the following two important advantages:

(1) Suppression of overshoot and undershoot
(2) Reduced granularity in low-density area

The algorithms for H-F processing and H-E processing are different, but the above two results are obtained in both cases by employing the following two techniques:

(1) Unsharping compensation for high-contrast area
(2) Unsharping compensation for high-frequency low-density area

An image to which the above two range compensation steps have been applied is called a density dependent blurred image. In the following, an example for H-F processing is used to explain the principles involved and the results that can be obtained.

(1) Blurring compensation for high-contrast area

The process by which overshoot and undershoot occur during conventional frequency enhancement processing is illustrated in Figure 9.

(1) is the original image, which comprises the high-contrast signal A and the low-contrast signal B. (2) is the result of subjecting this image to an averaging process. In the blurred image, the difference between contrast signals A and B has become very small, due to the influence of adjacent pixels on the averaging process. Therefore in the differential image (3) of the original image and the blurred image, signal component A is enhanced more strongly than signal component B. In the processed image (4) where the differential components have been added to the original image, the high-contrast signal has become even further enhanced. This results in a strong edge effect in high-contrast sections, such as for example parts of an image showing artificial bone, leading to overshoot and undershoot.

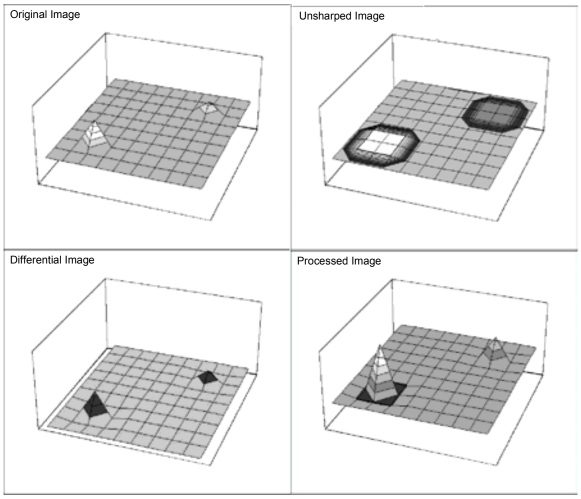


Fig. 9 Conventional frequency processing algorithm

In H processing, the compensation value calculated according to the function of Figure 8 is added to the blurred image (2)' of Figure 10. As explained above, the stronger the contrast of the original signal, the higher the compensation value. The compensated image therefore becomes a blurred image that reflects the contrast of the original image. In the differential image (3)' of the unsharped image and original image, extraction of components corresponding to high-contrast signals is limited. As a result, the processed image (4)' which is obtained by adding the differential image to the original image shows less emphasis of high-contrast sections than the processed image (4) obtained with conventional processing. In this way, low-contrast sections are enhanced as before, but enhancement of high-contrast area is reduced, yielding better clarity while at the same time controlling overshoot and undershoot.

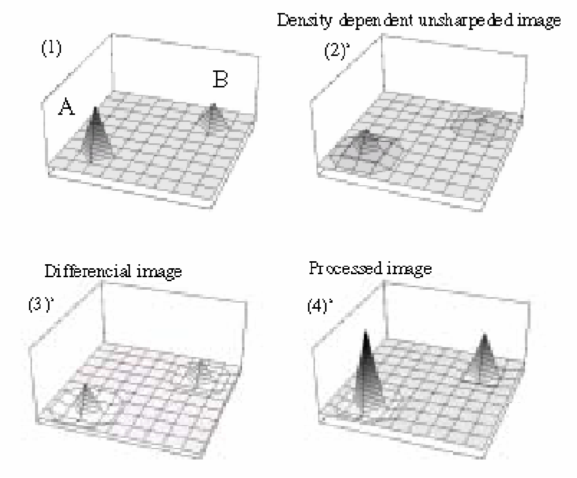
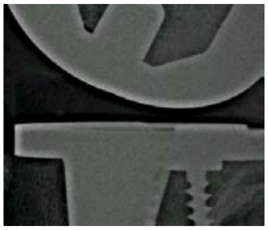


Figure 11 shows a processing example for an image of an artificial knee joint bone. With H processing, there is much less overshoot and undershoot around the image sections showing the artificial bone than with conventional processing.

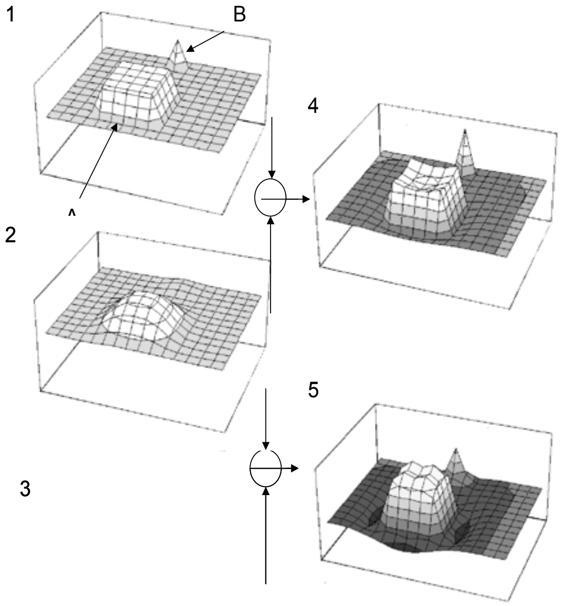


Conventional

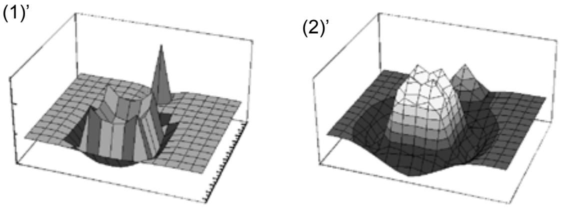
Hybrid

(2) Unsharping compensation for high-frequency low-density area

By applying unsharped image compensation only to high-frequency area with low density, it is possible to reduce high-frequency noise in low -density area while at the same time enhancement the representation of the human anatomy. A model for this processing technique is shown in Figure 12. Image (1) comprises the low-frequency signal area A and high-frequency signal area B. A is assumed to be an important area for diagnosis, such as a bone edge, whereas B is assumed to be high-frequency noise causing increased granularity of the image.

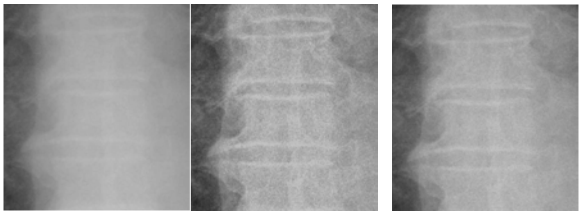


By performing repeated averaging processing for (1), the unsharped images (2) and (3) are generated. Subtracting these from the preceding unsharped image (or original image) results in the differential images (4) and (5). As can be seen from the illustrations, (4) mainly extracts the noise components concentrated in the high frequency bands, while (5) extracts mainly the human anatomy sections concentrated in the low frequency bands.In Figure 13, the result of adding both the extracted differential components (4) and (5) to the original image is shown as (1)', and the result of adding only the low-frequency differential components to the original image as (2)'.



As compared to (1)', the image (2)' where no high-frequency components were added shows less enhancement of noise components and stronger enhancement of human anatomy. In H processing, low-density area where noise can easily become a problem are turned into a density dependent unsharped image (by adding appropriate compensation to the image), and the degree of differential image addition is optimized for the respective frequency band. This allows fine tuning in order to suppress high-frequency noise and provide improved enhancement of human anatomy.

Figure 14 shows an example of applying H-F processing to a thoracic vertebra image. The image at right has been subject to the processing steps described above. As compared to the center image, where all frequency bands were enhanced equally, noise components are suppressed more efficiently while the vertebral body and other edge sections of the human anatomy come out more clearly.



Gradation processing only **No high frequency suppression** **With high frequency suppression**

In H-E processing, the density dependent unsharped image is also subject to unsharping compensation for high-contrast area, similar to H-F processing. By compressing the high-contrast edge area together with the low-frequency components, dynamic range is controlled to limit overshoot and undershoot.

At the same time, the tendency towards worsened granularity is also checked. Equalization processing tends to worsen granularity in low-density area due to the following two factors:

(1) The comparably low amount of radiation reaching the detector in low-density area is shifted into a more easily visible range by Equalization processing, leading to increased noise.

(2) Density compensation causes the gradation curve of low-density area to approach the high <gamma> area, leading to increased noise.

H-E processing counters the above outlined tendencies towards increased granularity by actively compensating high-frequency components in low-density areas using density dependent image unsharping. High-frequency components which have higher noise content in low-density areas are compressed together with low-frequency components. This allows Equalization processing while limiting the tendency towards worsened granularity.

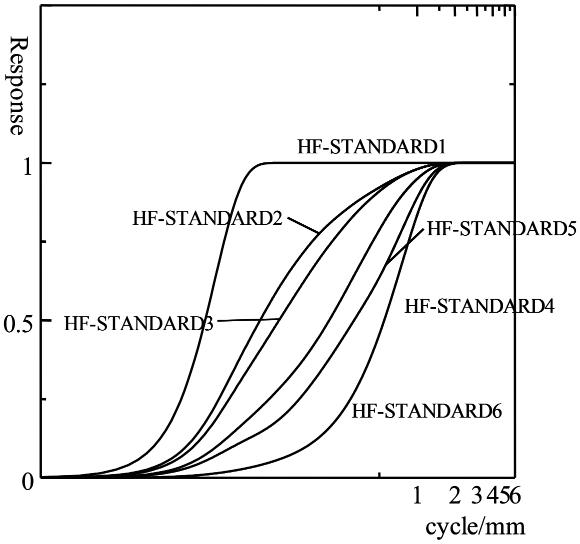
3. Parameters

Frequency response with H processing is determined by the two parameters HF-TYPE and HE-TYPE.

HF-TYPE

As shown in Figure 15, there are six settings, named HF-STANDARD 1 to 6. Higher numbers mean stronger enhancement in the high frequency band. An example for processing a cervical vertebra side view image is shown in Figure 16. Using the HF-STANDARD 1 setting that provides a stronger low-frequency focus, large parts such as the respiratory tract and soft tissue are clearly seen, with appropriate contrast for the entire image.

HF-STANDARD 6 on the other hand brings out smaller parts such as bone columns very well, and provides a sharp image.



H-F STANDARD1 H-F STANDARD6

- HE-TYPE

H-E processing comprises two settings with optimized frequency response, HE-STANDARD1 and HE-STANDARD2.

HE-STANDARD 1 enhances edge reproduction in low density sections, whereas HE-STANDARD 2 is designed to more effectively suppress granularity in low density area by compressing high-frequency components.

4. Conclusion

The above report outlines the technology and clinical effects of a new frequency processing technique called "H processing". This technique is based on decomposition into multiresolution space and aims at further improving diagnostic image quality. H processing solves some problems of conventional processing and allows flexible control over the sharpness of the image, to suit specific diagnostic purposes. The technique is expected to contribute to progress in the field of diagnostic imaging.

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