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EVALUATION OF A NOVEL METHOD OF NOISE REDUCTION USING COMPUTER-SIMULATED MAMMOGRAMS

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A novel method of noise reduction has been tested for mammography using computer-simulated images for which the truth is known exactly. This method is based on comparing two images. The images are compared at different scales, using a cross-correlation function as a measure of similarity to define the image modifications in the wavelet domain. The computer-simulated images were calculated for noise-free primary radiation using a quasi-realistic voxel phantom. Two images corresponding to slightly different geometry were produced. Gaussian noise was added with certain properties to simulate quantum noise. The added noise could be reduced by >70% using the proposed method without any noticeable corruption of the structures. It is possible to save 50% dose in mammography by producing two images (each 25% of the dose for a standard mammogram). Additionally, a reduction of the anatomical noise and, therefore, better detection rates of breast cancer in mammography are possible.

INTRODUCTION

The purpose of this study was to test a newly developed method for reducing the contribution of non-correlated noise components to radiographic images(1). The novel method is based on comparing two images obtained with slightly different geometry, but can also be used for two images sharing the same geometry as can be achieved by placing two imaging plates in one cassette separated only by a thin paper layer. The images are compared at different scales, using a cross-correlation function as a measure of similarity to define the necessary image modifications in the wavelet domain. Formally, a wavelet coefficient at some scale is given weighting proportional to the value of the corresponding correlation matrix in the given location(1). This method is based on the idea of measuring anatomical noise(2,3). If the method is used on two images resulting from two detection processes of the same exposure, these should only deviate by means of quantum and detector noise. By using the proposed method on such images, the quantum noise and the detector noise should be reduced greatly without reducing anatomical structures as long as these structures are not corrupted by noise. If two detection processes of two exposures with slightly different geometric conditions are the basis of this noise reduction, quantum noise, detector noise and anatomical noise are reduced by this method. Theoretically, the method could in this case disturb structures. It must therefore be proven that this is not the case. This study tests the method in terms of its possibility to reduce noise without losing relevant structures using computer simulated mammograms, for which the truth is known exactly.

MATERIALS AND METHODS

To quantify the effect of noise reduction and to prove the de-noising possibility a set of images with known noise components is needed. Optimal conditions would be as follows:

- All images without anatomical noise: just structures, quantum noise and detector noise. Anatomical noise is in this context defined as the noise component within a radiographic projectional image due to the patient and caused by the overlapping of many fine anatomical structures, which cannot be determined within the image as single structures(2,3).
- One image (A) without quantum and detector noise.
- Two images (B and C) containing the same or similar structures and each with the same amount of noise.

Such sets of images have been produced by using computer-simulated images(4) of an artificial high-resolution voxel phantom of the breast(5). Owing to the method of creation, this phantom is a very good

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representation of the structures and tissue compositions within the breast but nearly without anatomical noise (Figure 1). Simulated images have been calculated by using Monte Carlo calculations with a pixel size of 100 μm without quantum noise by using noise-free primary radiation (Figure 2, corresponding to (A)). Two images corresponding to focus–detector distances of 650 and 600 mm were produced. Gaussian noise was added to each pixel with a mean of zero and a variance per pixel proportional to the pixel value, which simulates the appearance of quantum noise. A series of image pairs was obtained with noise levels in the glandular region of each image ranging from 0.25 to 10%. The image with 10% noise and a focus–detector distance of 600 mm is shown in Figure 3. The noise reduction method was used on these pairs of images. For this study, we evaluated the three pairs with 2, 4 and 10% additional noise to simulate a real mammogram (2% additional noise) and mammograms collected with much lower doses.

RESULTS

The effect of the de-noising is shown in the regions of incidence (ROIs) of images with 4% added noise (Figure 4) and 10% added noise (Figure 5). In both figures (A) represents the ROI of the original noise-free image, (B) is the ROI with added noise, (C) is the de-noised ROI and (D) is the difference between (B) and (C). In Figure 6A (4% added noise) and 6B (4% added noise), the power spectra of the difference images of Figures 4D and 5D are demonstrated compared with those of the added noise, which can be obtained by building the difference between (B) and (A). The same ROI is shown in Figure 7 for the

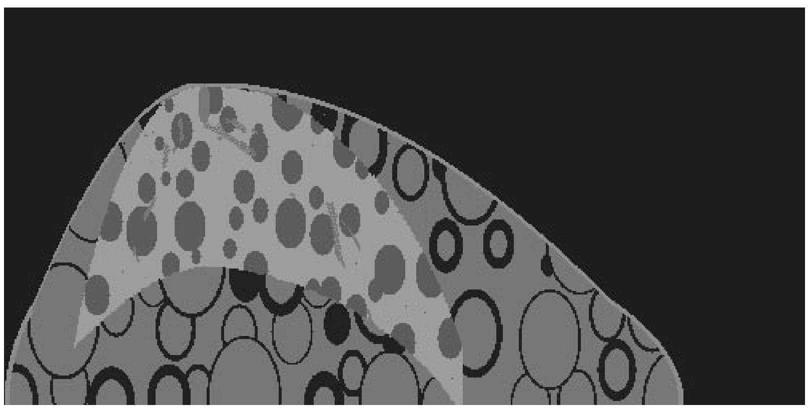

Figure 1. An Image of the structure of the used breast phantom, many layers of this resulting in the voxel phantom.

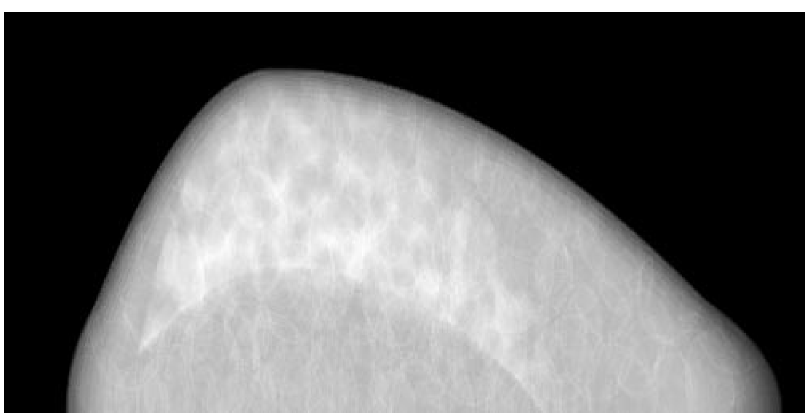

Figure 2. A simulated X-ray image resulting from a ray tracing through the voxel phantom. No quantum or detector noise is assumed.

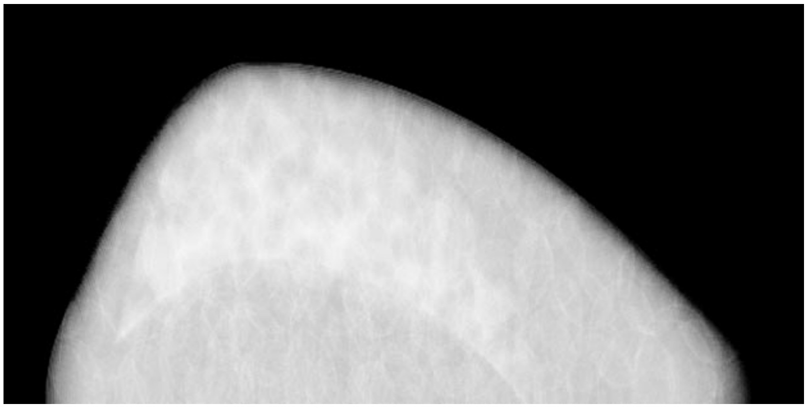

Figure 3. The same simulated image as in Figure 2 using a focus–detector distance of 600 mm with 10% added noise.

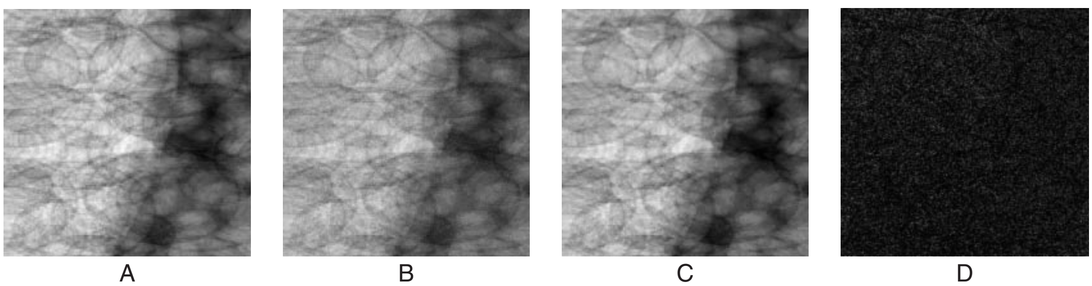

Figure 4. (A) A part (ROI) of the original noise-free simulated image; (B) the same ROI with 4% added noise; (C) the same ROI from the de-noised image; and (D) difference image between (C) and (A).

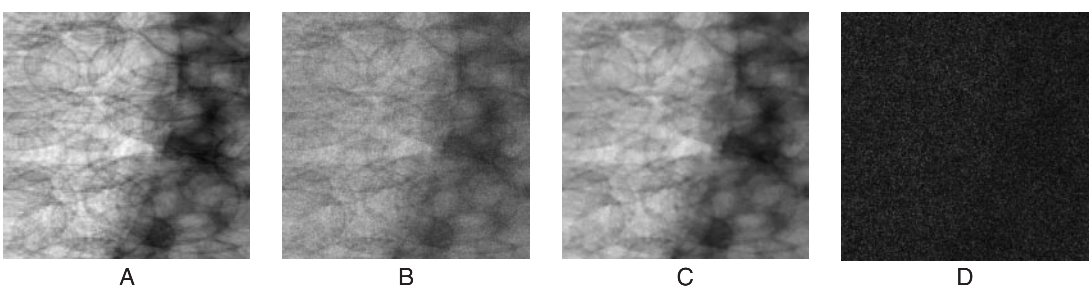

Figure 5. (A) A part (ROI) of the original noise-free simulated image; (B) the same ROI with 10% added noise; (C) the same ROI from the de-noised image; and (D) Difference image between (C) and (A).

original image with 2% added noise as a representation for a real mammogram.

The effect of de-noising on the appearance of the image is very evident. The noise can be reduced by 70% or more. The exact value for the reduction of the noise power depends on the number of approximation levels used for de-noising the images. For this reduction, a visual comparison of the re-constructed and the original images shows no noticeable corruption of the structures within the images, which means that the signal-to-noise-ratio is increased by about a factor of 4. This is also the result of the comparison of the noise power spectra shown in Figure 6. The power spectrum is nearly the same for the noise resulting as the difference between the de-noised image and the original one as for the noise resulting from the difference between the original and the noise-free image, which is the added

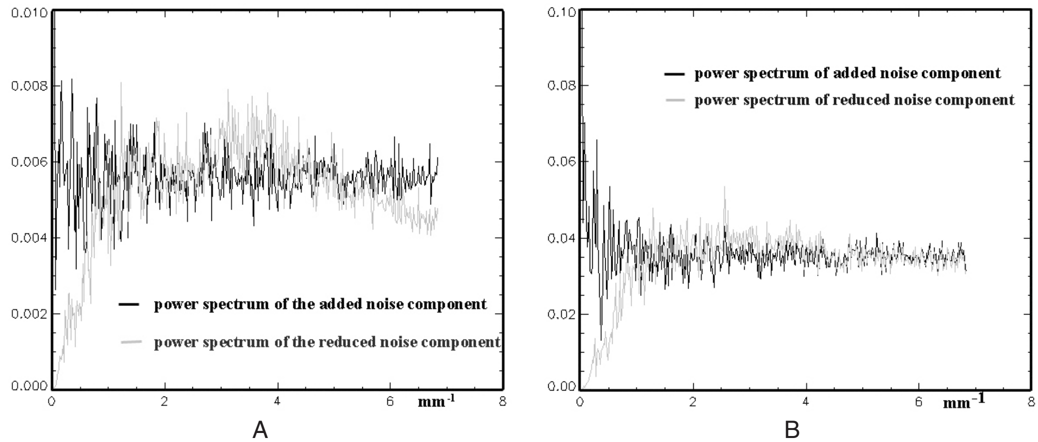

Figure 6. (A) The power spectra of the difference images in Figure 4D and (B) Figure 5D compared with the noise spectra of the corresponding added noise.

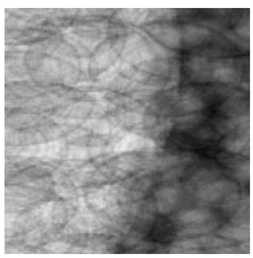

Figure 7. The same ROI as in Figures 4 and 5 is shown for the original image with 2% added noise as a representation for a real mammogram.

noise itself. We did not alter the wavelet coefficients for the lowest frequency components, because it was assumed that low-frequency structures do not corrupt the image interpretation very much and that the anatomical noise would, owing to its definition, have hardly any components in that frequency area.

The noise in the de-noised images of the pairs corresponding to much lower dose values is still lower than the noise in the image corresponding to an original mammogram (2% added noise) without any visible deterioration of the image structures.

CONCLUSIONS

The results of this study with images for which the truth is known exactly have shown that the method of noise reduction presented here and in former studies[1–3] allows the reduction of the technical noise (quantum and detector noise) so effectively that it is possible to save 50% dose in mammography. This can be achieved by producing two images (each 25% of dose). This also allows the removal of the anatomical noise and thus has the potential to improve breast cancer detection rates for mammography. There is no corruption of the anatomical structures that could be detected in the original image. The next step is to perform clinical trials on real mammograms produced with this new imaging and noise reduction technique. It should be highlighted in this context that by using this method the DQE of the detecting systems is not changed. The method just takes advantage of an additional information layer, which has not been previously used. It is, therefore, feasible to produce images with higher image quality using less patient dose in mammography, but this remains to be demonstrated by trials using clinical images.

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