Introducing a Novel Image Quality Measure for Digital Phase-Contrast-Image Evaluation

Satoru Matsuo[1], Hiroshi Fujita[2], Junji Morishita[3], and Tetsuro Katafuchi[4]

[1] Department of Radiology, Shiga University of Medical Science
Otsu 520-2192, Japan
matsuo@belle.shiga-med.ac.jp
[2] Department of Intelligent Image Information, Graduate School of Medicine, Gifu University
Gifu 501-1194, Japan
fujita@fjt.info.gifu-u.ac.jp
[3] Department of Health Sciences, Faculty of Medicine Science, Kyushu University
jm@shs.kyusyu-u.ac.jp
[4] Department of Radiological Technology, Gifu University of Medical Science
Seki 501-3892, Japan
katafuchi@u-gifu-ms.ac.jp

Abstract. Recently, detective quantum efficiency (DQE) arising from the concept of signal-to-noise ratio (SNR) has been used for assessing digital x-ray imaging systems. Using a phase-shift of x-rays that occurs when passing through an object, digital phase contrast imaging (herein referred to as "phase imaging"), which involves magnification, can produce images different from those of standard contact imaging (herein referred to as "regular imaging"). For this reason, assessment of the image quality based on DQE which does not include the object information may not be appropriate to compare image quality between the phase images and the regular images. As an alternative method, we proposed a new image quality assessment method based on radial direction distribution function (RDDF) and signal intensity distribution function (SIDF) in two-dimensional power spectra of images that contain information of an object. To evaluate the usefulness of our method based on RDDF and SIDF, we assessed images of different contrast, noise characteristic and sharpness using simple phantoms. Our results showed that the accurate evaluation of these factors was successfully performed. Comparing the image quality of projected plant seeds by phase imaging and regular imaging, we found the phase imaging method provided higher image quality in terms of edge sharpness than that of the regular imaging.

Keywords: phase contrast imaging, radial direction distribution function, signal intensity distribution function, edge enhancement, two-dimensional power spectra.

1 Introduction

For evaluation of digital x-ray imaging systems, detective quantum efficiency (DQE) is sometimes applied based on the concept of signal-to-noise ratio (SNR).[1, 2] This is because DQE has been considered useful for comprehensive evaluation of an x-ray

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detection system, as data calculations of DQE are done using the gradient obtained with input-output conversion characteristics of the system (characteristic curve), modulation transfer function (MTF) for resolution properties, and the Wiener spectrum or noise power spectrum for noise properties [3]

For image evaluation of digital phase contrast imaging developed for mammography examination, the authors have been conducting comparative studies between conventional digital x-ray imaging (herein referred to as "regular imaging") and new phase contrast imaging (herein referred to as "phase imaging") using simple phantoms [4-9]

The feature of the phase imaging is to provide edge-enhancement of an imaged object, utilizing refracted x-rays which occur when x-rays pass through the object. Therefore, phase imaging should be assessed based on the distribution of x-ray intensities after passing the object, including the refracted x-rays. Namely, to assess differences between the phase images and regular images, conventional methods are not appropriate, such as MTF that has been used to evaluate feature of an x-ray detector without including an imaged object, Wiener spectrum, DQE, or noise equivalent quanta (NEQ) that has been used for image quality evaluation. In this study, we proposed a new image evaluation method including an imaged object, utilizing radial direction distribution function (RDDF), which was obtained based on two-dimensional (2D) power spectrum (herein referred to as "power spectrum") [10-14].

2 Materials and Methods

The system used in our experiment (Mermaid, Konica Minolta, Tokyo, Japan) consists of mammography x-ray equipment (MGU-100B, Toshiba, Tokyo, Japan) capable of performing regular imaging and phase imaging and a data reader (REGIUS MODEL190, Konica Minolta, Tokyo, Japan) which includes a photostimulable phosphor plate of Computed Radiography (PM-6M, Konica Minolta, Tokyo, Japan) for the x-ray detector. A molybdenum x-ray tube with a 0.1 mm / 0.3 mm focal spot size was used, in which selection of the size was automatically done (a 0.3 mm size was used for regular imaging and a 0.1 mm size was used for phase imaging). The distance between the focal spot of the x-ray tube and the target object was 65 cm. In regular imaging, the detector was positioned right behind the object; whereas, in phase imaging, the detector was positioned 49 cm apart from the object. Therefore, in phase imaging, the imaged object was magnified by 1.75-times.

The parameter of the system had a sampling pitch of 0.04375 mm, matrix size of 4360 × 5736, and density resolution of 12 bits. Therefore, the effective sampling pitch at 1.75-time magnification imaging was 0.025 mm.

Data analysis was conducted after transferring the raw digital image data of the imaged phantom to a personal computer and post-processing the data. Power spectrum was obtained by 2D Fourier transformation of images.

$p\ (r)$ and $p\ (\theta)$ are the sum total of power spectrum in spatial frequency regions; a round-shape and fan-shape, as shown in Fig. 1 (a) and (b), respectively. The $p\ (r)$ is defined as RDDF that shows the degree of texture roughness. The $p\ (\theta)$ can be defined as ADDF, which shows the direction of texture.

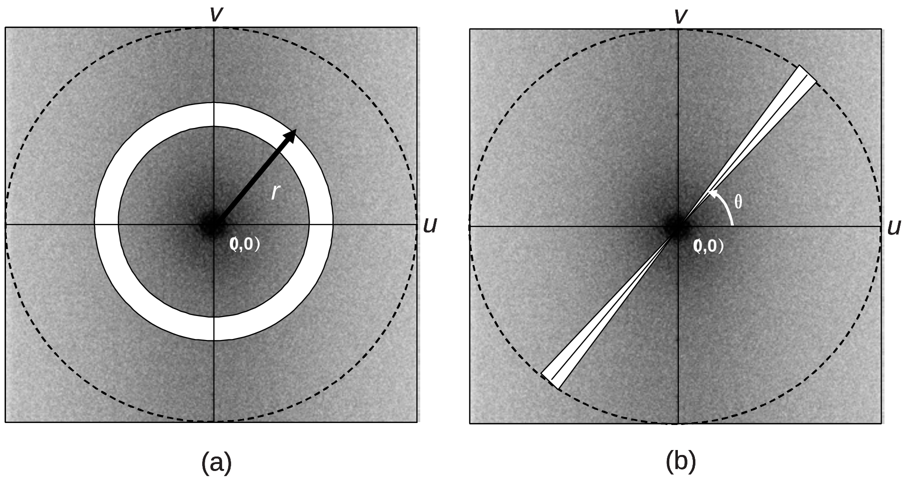

Fig. 1. The concept of (a) radial direction distribution function (RDDF) of the power spectrum, $p\ (r)$ and (b) angle direction distribution function (ADDF) of the power spectrum, $p\ (\theta)$

Next, as shown in the following Eq. (1), by using a logarithm of ratio between the $p_{s+n}\ (r)$ of "signal + noise" image and $p_n\ (r)$ of "noise" image, subtraction of $p_n\ (r)$ from $p_{s+n}\ (r)$ is done, and thus RDDF of only "signals" is obtained. In the present study, we defined this as signal intensity distribution function (SIDF), that is $P_s\ (r)$.

$$P_s(r) = 10\,log_{10} \frac{p_{s+n}(r)}{p_n(r)} \quad \text{[dB]} \tag{1}$$

In this study, as our purpose was to evaluate sharpness of x-ray images, image quality difference between phase images and regular images were evaluated using RDDF $p\ (r)$ (for spatial frequency component evaluation) and SIDF $P_s\ (r)$ obtained from $p\ (r)$.

To evaluate usefulness of our image evaluation method applicable when including the subject information by RDDF and SIDF, we used two types of simple phantoms which provide different levels of contrast, sharpness and noise, independently.

Secondly, image quality of phase images and regular images was compared using plant seeds (including grains of rice embedded in glue) having major axes of 4 -5 mm.

3 Results and Discussion

RDDF and SIDF obtained from spherical phantom images with different contrast are shown in Fig. 2 (a) and (b), respectively. Although the difference of image contrasts cannot alter the shapes of the curves of RDDF or SIDF, it can be shown as different levels of RDDF or SIDF in all frequencies. These facts helped to accurately analyze the difference of contrasts.

RDDF and SIDF obtained from spiked-ball phantom images with different sharpness are shown in Fig. 3 (a) and (b). Difference of image sharpness was clearly shown in the different RDDF or SIDF curve shapes and their levels in the frequency band areas between 0.2 and 2.5 cycles/mm, although those were not different in the low frequency

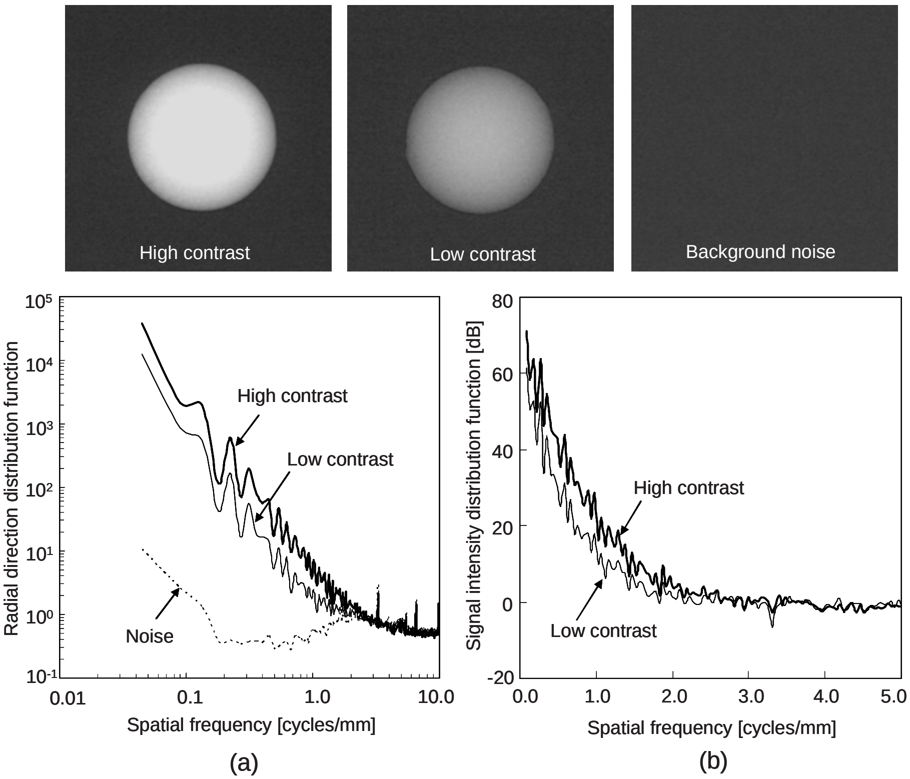

Fig. 2. Radial direction distribution functions (RDDFs) (a) and signal intensity distribution functions (SIDFs) (b) for high and low contrast phantom images as well as for the noise image

band areas. When the sharpness is different, a spatial frequency band area recognizable as signals is altered. These results provide accurate analysis of the sharpness difference.

RDDF obtained from different noise images (Fig. 4 (a), (b)) are shown in Fig. 4 (c). Using the same detector, the difference of noise characteristic of these images occurs only in the low frequency region, as these reflect difference of quantum noise only. The results clearly reflect the noise difference.

RDDF and SIDF of the phase image and regular image are shown in Figs. 5 (a) and (b), respectively. Frequency band of signals is considered different between regular images and phase images, as signal component of phase images contains signals up to 6.0 cycles/mm, though that of regular images becomes 0 dB at 3.0 cycles/mm. These results concur with the difference in sharpness observed with image evaluation of the simple phantom (as shown in Fig. 3), and that phase images provide better sharpness than regular images. Based on the images of plant seeds with RDDF or SIDF, we consider the image quality improvement by phase imaging was resulted from improvement of image sharpness, and the causes must be the scaling effect derived from magnification imaging and edge enhancement effect due to refracted x-rays.

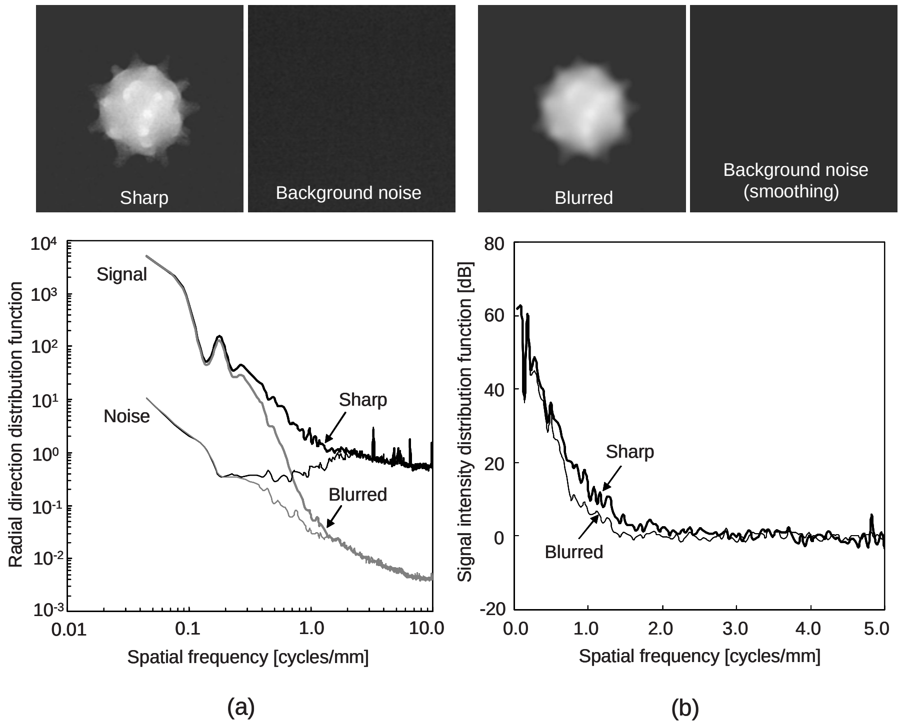

Fig. 3. Radial direction distribution functions (RDDFs) of the spiked spherical phantom images of different sharpness and with the different level of noise (a). Signal intensity distribution functions (SIDFs) of the spiked spherical phantom images having different sharpnesses (b).

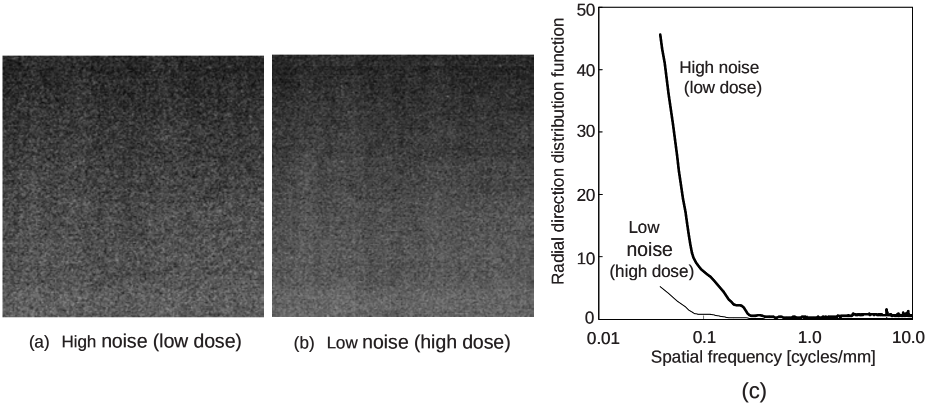

Fig. 4. The noise images by the difference in a dose. (a) high noise image (dose : 5mAs) and (b) low noise image (dose : 16mAs). (c) Radial direction distribution functions for high and low noise images.

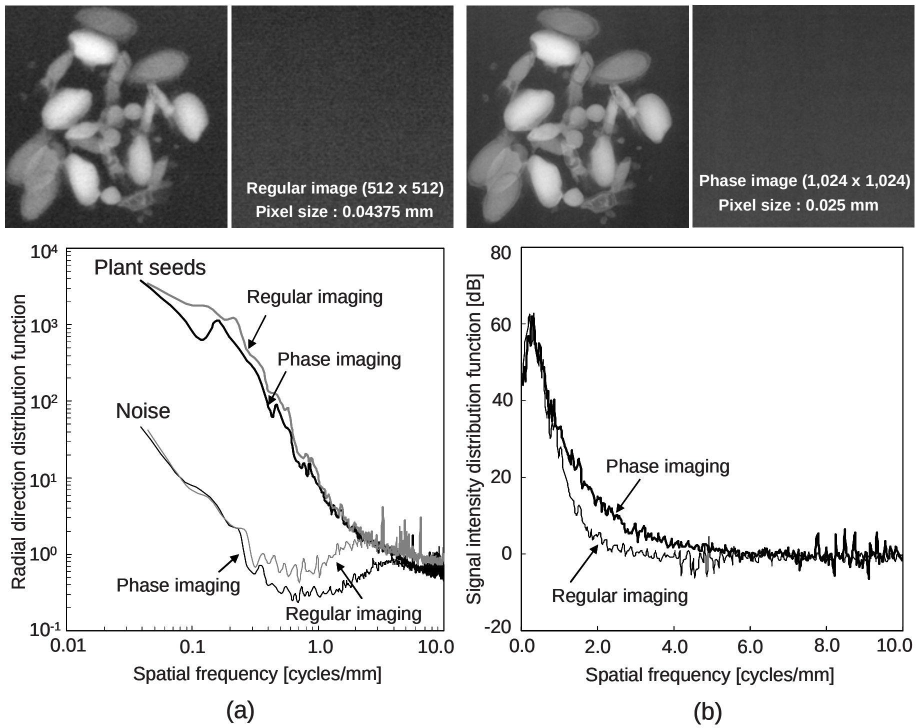

Fig. 5. Radial direction distribution functions (RDDFs) of plant seeds and noise images for the phase imaging and regular imaging (a). Signal intensity distribution functions (SIDFs) of plant seeds images for the phase imaging and regular imaging (b).

4 Conclusion

In this study, using phantoms, we investigated whether image quality evaluation was possible between different images, using RDDF and SIDF which were obtained from power spectrum. The results of our experiment proved that differences of image contrast and sharpness could be correctly evaluated. This method is effective for phase imaging, where evaluation of sharpness is impossible without images containing information of the scanned object.

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