An improvement in automatic MTF measurement in CT images using an edge of the PMMA phantom

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Abstract. We have developed an improved method of modulation transfer function (MTF) measurement using an edge of the polymethyl methacrylate (PMMA) phantom which is normally positioned for computed tomography dose index (CTDI) measurement. In CTDI measurements, the peripheral holes of the PMMA phantom are set at the 3, 6, 9 and 12 o'clock positions. The upper edge of the phantom image has a hole, which precludes its use in calculating the MTF. To circumvent this, the phantom image was homogenized by replacing all pixel values inside the phantom with the median value of the phantom pixels. Subsequently, we were able to calculate the MTF by measuring the edge spread function (ESF) curve, calculate the line spread function (LSF) curve, and obtain the MTF curve by Fourier transform. The resulting MTF curve using our proposed method was then compared with the tail replacement method which had been proposed previously. Our method is superior to the tail replacement method which results in some inhomogeneity of the ESF curve in the part inside the phantom.

1. Introduction
CT is an effective X-ray imaging modality for acquiring cross-sectional images to assist in diagnosing diseases and disorders in patients. The quality of the images is determined by several parameters, one of which is spatial resolution [1, 2]. Images with poor spatial resolution can lead to misdiagnosis of a disease, so that spatial resolution should be regularly monitored as an integral part of a quality control (QC) program [3].

Spatial resolution can be determined using a line pair image [3, 4], but the technique is very subjective. A more objective determination of spatial resolution can be achieved using the modulation transfer function (MTF) [5], which can be obtained from the edge spread function (ESF), the line spread function (LSF), or the point spread function (PSF). The standard method to obtain the MTF is by using a wire or bead image [2, 5].

Previously, Anam et al. [6] introduced a new algorithm for obtaining the MTF automatically using an edge of a polymethyl methacrylate (PMMA) phantom [6], and
reported that the results using their method were comparable to those using the standard wire method [6]. Their approach is useful in developing countries, such as Indonesia, whose hospitals are unlikely to own specialized phantoms for determining image quality. However, the MTF measurements use the upper edge of phantom and require homogeneity close to the edge. The phantom has to be rotated 45° for MTF measurement [6] so that the peripheral holes are not at the 3, 6, 9 and 12 o’clock positions usually used for CTDI measurement. If the phantom placement is not rotated by 45°, then there is an inhomogeneity in the area near the upper edge of the phantom due to a small hole used in the placement of the pencil ionization chamber [7]. For this reason, an additional scan of the phantom is needed to obtain the rotated image of PMMA phantom.

A development in MTF calculations for non-homogeneous objects was proposed by Sanders et al. [8]. Their tail replacement technique was used to overcome the homogeneity of the ESF curve by replacing the non-homogeneous right end of an ESF curve by the homogeneous left end. This tail replacement technique has been validated by Anam et al. [9] using the TOS phantom. In this current study, we have developed a new technique for overcoming the non-homogeneous PMMA phantom by homogenizing it using the median pixel value of the phantom. We have compared this proposed method with the tail replacement method.

2. METHOD

Phantom position and proposed method

The phantom used in this study was the PMMA head phantom. The phantom is 16 cm in diameter and contains five small holes used in placing the pencil ionization chamber, one in the middle and four around the circumference at 90° apart and 1 cm from the edge. This phantom was scanned by a Siemens Somatom 6 CT installed at Diponegoro General Hospital (RSND) with input parameters: tube voltage of 130 kVp, tube current of 132 mA, 1 second rotation time, 5 mm slice thickness, axial mode, and field of view (FOV) of 24 cm.

Figure 1(a) shows the position of the PMMA phantom for CTDI measurement. Figure 1(b) depicts the PMMA position for MTF measurement as previously proposed [6]. It shows that phantom holes in the scanning process were rotated 45° from their original position.

Figure 1. Schematic of a phantom image with (a) holes at position 3, 6, 9, and 12 o’clock (b) phantom rotated by 45°.
1. The standard PMMA phantom position as in Figure 2(a), cannot be used to calculate the MTF from the resulting ESF because of the inhomogeneity in the upper edge of the phantom. To overcome this inhomogeneity the median of the pixel values of the whole phantom image is calculated and used to replace all the pixel values. The homogenized phantom image is shown in Figure 2(b).

![Figure 2. Image of PMMA phantom (a) before homogenization, (b) after homogenization.](image)

2.2 MTF calculation
The ESF curve was differentiated to calculate the LSF curve. The LSF curve was then normalized, by setting the MTF value at 1 for a spatial frequency of 0. The LSF curve was then Fourier transformed to obtain the MTF, and the 50% MTF calculated from the MTF curve. The accuracy of the new method in obtaining ESF and MTF will be compared with the tail replacement developed by Sanders et al. [8] on the standard phantom position for CTDI measurement (i.e. non-rotated phantom). In addition, result of the proposed method on the standard phantom position was compared with the rotated phantom using previous method [6]. The MTF was calculated automatically using MatLab software.

3. Result
3.1 MTF in a non-rotated phantom
The resulting ESF, LSF, and MTF curves for standard PMMA phantom position, before and after homogenization, are shown in Figure 3. Figure 3(a) shows that before homogenization, the right end of the ESF curve decreasing, and it is consistently straight at the right end after homogenization. Figure 3(b) shows that the result of the LSF curve after homogenization is consistently straight at the right end. Figure 3(c) shows the MTF curve before homogenization fluctuates and has a peak at about 3.5, while after homogenization it is bell-shaped as expected. The 50% MTF values before and after homogenization are 0.51 cycle/mm and 0.31 cycle/mm, respectively.

![Figure 3. Comparison of curves before homogenization (blue line) and after homogenization (red line). (a) ESF curve, (b) LSF curve, (c) MTF curve.](image)
3.2. Comparison with the tail replacement method
The comparisons of the tail replacement method [8] and the currently proposed method on the ESF, LSF and MTF curves are shown in Figure 4. Figure 4(a) shows that the ESF curve from the tail replacement method has a slight decrease in the right end of the curve, while using the proposed method has none. As a result of the LSF curve from the tail replacement method has a downward peak as shown in Figure 4(b), while in the proposed method the LSF curve does not. Figure 4(c) shows the MTF curve with the tail replacement method and the proposed method. The results of 50% MTF for the tail replacement method and the proposed method are 0.32 cycle/mm and 0.31 cycle/mm respectively.

![Image](image_url)

**Figure 4.** Comparison of the proposed method (red line) with the tail replacement method (blue line). (a) ESF curve, (b) LSF curve, (c) MTF curve.

3.3. Comparison with the rotated phantom
The result of the proposed method on the standard phantom position for CTDI measurement (i.e. non-rotated phantom) (Figure 1(a)) was compared with the rotated phantom (Figure 1(b)) using previous method [6]. The comparisons for the ESF, LSF and MTF curves are shown in Figure 5. It can be seen that our proposed method on the non-phantom position for CTDI measurement produces very similar results compared to the rotated phantom. The value of 50% MTF is 0.31 cycle/mm for both positions.

![Image](image_url)

**Figure 5.** Comparison of curves for standard phantom position (i.e. non-rotated phantom) using the proposed method and the rotated phantom position. (a) ESF, (b) LSF, (c) MTF.

4. Discussion
Spatial resolution is one of the important parameters in determining image quality. It is important to pay attention to image quality, because the resulting image from CT will be used
in diagnosing illnesses. A comprehensive metric to describe the spatial resolution is the MTF [10]. The standard method for obtaining MTF is by using a wire or a bead image [2, 5]. One study has reported that MTF could be determined using the CTDI phantom [6]. However, the phantom should be rotated about 45° so that there is no hole in the upper edge [6]. Therefore, if we want to measure MTF, we cannot use the image of CTDI phantom directly. It would have to be re-scanned after a 45° rotation. We have introduced a new technique, which uses homogenization with the median of the phantom pixel values, as an alternative to the tail replacement method [8].

Based on our results, the tail replacement technique [8] causes a slight decrease in the ESF at the right end of the curve while using our proposed method the ESF curve is flat. This results in a smoother MTF function when using our method. To evaluate the effectiveness of the proposed method, we compared the results obtained using our method with the standard phantom position for CTDI measurement and rotated phantom using the standard method [6]. The 50% MTF is 0.31 cycle/mm for both, indicating the accuracy and effectiveness of our proposed method.

Our proposed method represents a significant improvement for calculating the MTF of non-homogeneous objects. With this method, it is possible to calculate CT doses and spatial resolution simultaneously on the same images without repeating scans, saving time and additional effort. This automatic MTF calculation algorithm is simple and fast, and requires no user intervention.

5. Conclusion
A method to improve the automated MTF calculation using a PMMA phantom which is normally positioned for CTDI measurement has been proposed. The method replaces pixel values inside the phantom with the median pixel value of the phantom itself. The method is more accurate than using tail replacement, and uses the same image as in CTDI without the need for additional scans. It produces a very similar MTF curve using a homogeneous phantom. This method is easy to apply in clinical applications, because it is fast and requires no user intervention.

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