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Cite as: AIP Conference Proceedings **2346**, 040009 (2021); https://doi.org/10.1063/5.0047720
Published Online: 29 March 2021

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An Automation of Radial Modulation Transfer Function (MTF) Measurement on a Head Polymethyl Methacrylate (PMMA) Phantom

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Abstract. The measurement of modulation transfer function (MTF) using a head polymethyl methacrylate (PMMA) phantom has been introduced previously. However, measurement is performed using a rectangular region of interest (ROI) at the upper edge of phantom. The purpose of this study is to automatically measure radial MTF using a head PMMA phantom.The head PMMA phantom was scanned using CT scanner in axial mode. Software for an automated radial MTF measurement was developed with MATLAB. The steps of automated measurement were started with segmentation and determination of the center of the image. From the center of the phantom then lines were drawn radially so that it passed over the edge of the phantom. These lines indicated the ROIs for MTF measurement. The profiles of the ROIs were taken. The profiles were then averaged to obtain a single profile called edge spread functions (ESF). The ESF was differentiated to get line spread function (LSF). The Fourier transformation was applied to the LSF to get the MTF. The MTFs resulted from the proposed method were compared to those obtained using a rectangular ROI, different CT scanners, and filters.The software for an automated radial MTF using a head PMMA has been proposed and successfully developed using MATLAB. The MTF 50% values for the rectangular and radial ROIs are 0.30 ± 0.00 cycles / mm and 0.32 ± 0.00 cycles / mm, respectively. The MTF10% values for the rectangular and radial ROIs are 0.58 ± 0.00 cycles / mm and 0.59 ± 0.00 cycles / mm, respectively. This software for automated radial MTF can be used for different CT scanners and different filters. So, it indicates that the radial MTF on the head PMMA phantom is more accurate than rectangular MTF.

INTRODUCTION

CT image quality is usually monitored by the medical physicist with quality control (QC) procedure. One of the image quality parameters is spatial resolution [1-2]. Spatial resolution indicates sharpness of the CT image [3] and shows the CT performance. The objective quantification of spatial resolution is represented by the MTF. The MTF usually has y-axes values of 0-1. However, because of filtering in the image reconstruction, it sometimes has a value more than unity [4]. The y-axes MTF of 1 indicates that the object has been scanned very well, while the y-axes MTF of 0 indicates that the imaging system cannot transfer the object to the image [5]. The y-axes MTF of 0.1 (10% MTF) is the cut-off value indicating a limit of spatial resolution of the image. In clinical CT images, the cut off is in the range of 0.5-2 cycle/mm. The MTF can be determined by several methods, such as the point spread function (PSF) [6], the line spread function (LSF) [7], and the edge spread function (ESF) [8]. The PSF, LSF, and ESF are measured on point, line, and edge objects, respectively [6-8].

The MTF is usually measured using specific phantoms, such as the American College Radiology (ACR) [9] and CatPhan 500 phantoms [10]. However, those phantoms are rarely owned by most hospitals in Indonesia. So, an alternative phantom is needed to be conducted for MTF measurement. There are studies to measure MTF in CT using PMMA phantom [11-12]. Anam et al developed a method to automatically measure MTF using an edge of the

Proceedings of the International Conference and School on Physics in Medicine and Biosystem (ICSPMB)
AIP Conf. Proc. 2346, 040009-1–040009-6; https://doi.org/10.1063/5.0047720
Published by AIP Publishing. 978-0-7354-4087-6/$30.00

PMMA phantom which must be rotated 45 degrees to avoid the upper hole for an ionization chamber pencil. This upper hole would yield inhomogeneity in the image and lead to incorrect MTF. That study used a rectangular ROI which was placed at the top of the phantom [11]. Recently, Hak et al improved the MTF measurement using the PMMA phantom without 45 degrees rotation, because the PMMA phantom was homogenized by replacing the pixel value within the PMMA phantom with its median pixel value [12]. MTF measurement with homogenization method can be more effective because MTF measurement can be simultaneously conducted with CT dose measurement.

The use of rectangular ROI may decrease the MTF value due to the detected curvature edge is linearly averaged. More accurate MTF may be obtained by the radial ROI [13]. The current study develops an automatic MTF using radial ROI along the edge of the head PMMA phantom. In the clinical applicant, the accurate selection of filter was important to support the accuracy in diagnosis. So in this study, we will examine the algorithm with different filters and CT scanners.

MATERIALS AND METHODS

ROI Determination

In this study, the image of the head PMMA phantom was used. This phantom image was scanned with a Siemens Emotion 16 CT scanner with parameters of 130 kVp, 240 mA, 1 second rotation time, slice thickness of 1.5 mm, 19.2 cm field of view (FOV), and axial mode. The phantom position was not rotated.

We used different CT manufacturers to examine whether the algorithm could be used on other CT manufacturers. The phantom was scanned using a Toshiba Alexion 4 CT scanner with three different filters, i.e. FC13, FC30, and FC52. The parameters of scanning were 20 cm of FOV, 120 kVp, 100 mA, 1 s second rotation time, slice thickness of 2 mm, and axial mode. In this case, the phantom was rotated 45 degrees. 3 different filters are used to examine the algorithm whether it can differentiate filters or not.

This study improved an algorithm proposed by Anam et al [11]. The ROI determination was automatically carried out. The position and shape of a rectangular ROI were shown in Fig. 1(a). The size of the ROI was 41 x 41 pixels. Fig. 1(b) showed the position and shape of the radial ROI. The length of each line was 41 pixels.

The first step of the radial MTF measurement was to open the CT image with the MatLab software. The second step was image segmentation, followed by the center of the phantom image determination. The radial ROI was formed by making a line from the center of the phantom so that it passed through the phantom edge. ROIs were formed one by one along the phantom edge, except in the ionization chamber pencil holes (Fig. 1(b)).

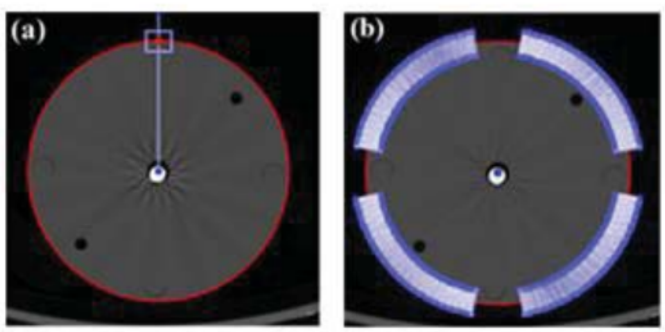

FIGURE 1. Different ROIs for measuring MTF on edge of the head PMMA phantom, (a) Rectangular ROI and (b) Radial ROI. There were no radial ROIs in 0, 90, 180, and 270 degrees to avoid holes of the head PMMA phantom for a pencil ionization chamber placement.

Each ROI has various angles (θ) which can be determined by the equation:

$$\theta = tan^{-1}\frac{y}{x} \tag{1}$$

Which x and y were the point coordinates of each ROI. These steps for radial ROI determination were shown in Fig. 2.

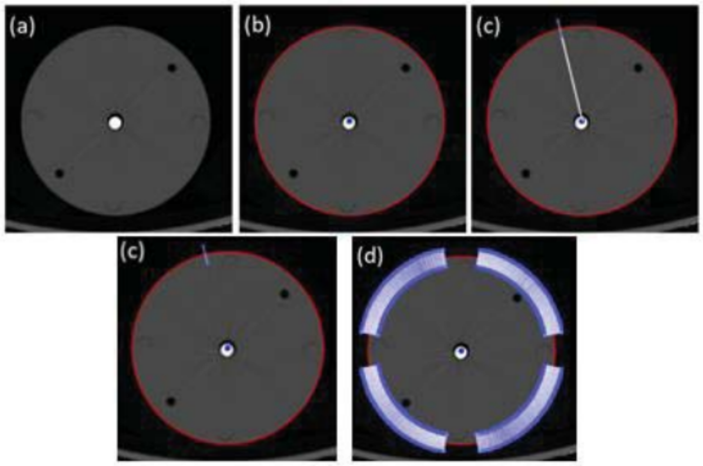

FIGURE 2. The steps of radial ROIs determination.

MTF Determination

Each ROI profile was taken and then all ROI profiles were averaged to produce single profile. The single profile was called ESF. Subsequently, the ESF was interpolated. This process can be seen in Fig. 3. Next, the ESF curve was differentiated to obtain the LSF curve. Finally, the MTF curve was obtained by Fourier transform of the LSF curve. The accuracy of radial MTF was compared with the rectangular MTF.

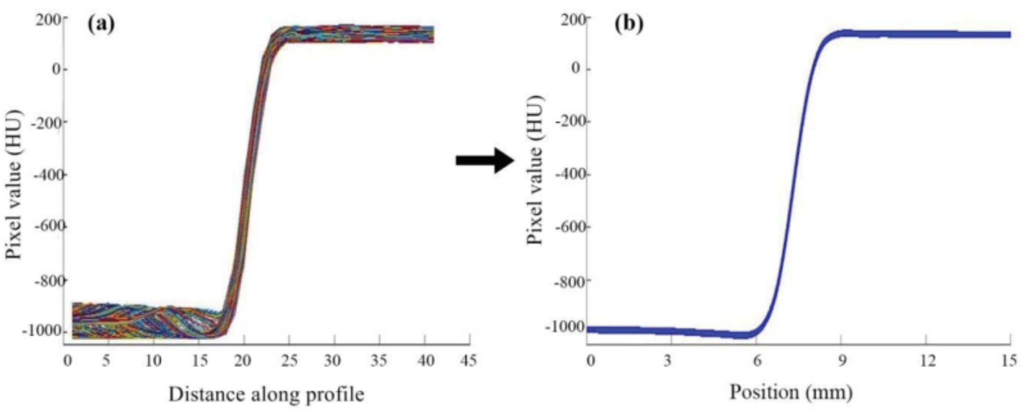

FIGURE 3. Determination of radial ESF. (a) All profiles from all ROIs, (b) Single averaged radial ESF from all profiles.

RESULTS AND DISCUSSION

We will examine the algorithm with different CT scanners. First, we used PMMA phantom without rotation scanned by a Siemens CT scanner. The results of LSFs and MTFs with radial ROI and their comparison with the rectangular ROI method [11] can be seen in Fig. 4. The LSF curves between the proposed method and the previous method are different. The LSF tail of the proposed method is straight and the right of the LSF curve of the previous method [11] is inhomogeneous due to the hole within the phantom. Therefore, the MTF curves from the proposed and previous methods[12] are also seen differently. The MTF curve from the proposed method is smooth, whereas MTF from the previous method is not smooth. The MTF 50% values for the rectangular and radial ROIs are 0.30 ± 0.00 cycles/mm and 0.32 ± 0.00 cycles / mm, respectively. The MTF10% values for the rectangular and radial ROIs are 0.58 ± 0.00 cycles/mm and 0.59 ± 0.00 cycles/mm, respectively.

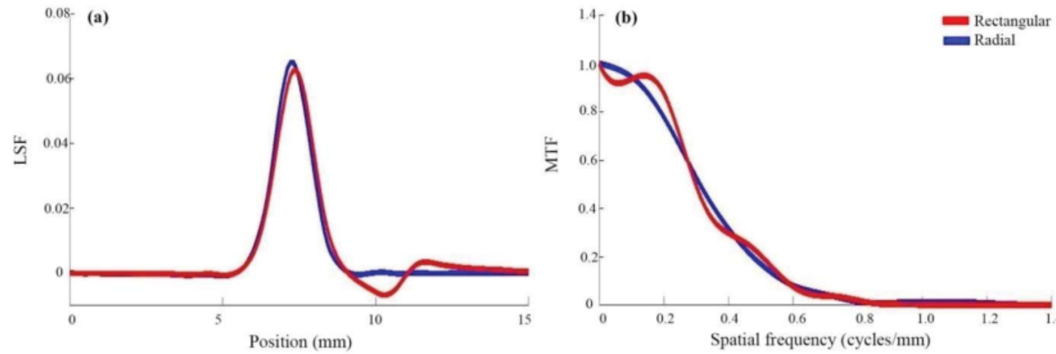

FIGURE 4. Comparison of (a) LSF curves and (b) MTF curves between the radial ROI with the rectangular ROI.

Then, we compare MTF using radial ROI with rectangular ROI with the homogeneous method to eliminate inhomogeneous due to pencil holes [12]. The comparison of the LSFs and MTFs between the radial ROI and the rectangular ROI with the homogeneous methodscan be seen in Fig. 5. The LSF curve of the proposed radial method can be seen slightly higher than the rectangular ROI with the homogeneous method. Consequently, the MTF curve of the proposed method decreases slower than the homogeneous method. It indicates that measures spatial resolution using radial ROI is slightly greater than measurement using the rectangular ROI with the homogeneous method. The 50% MTFs of the radial proposed method and the rectangular ROI with the homogeneous method are 0.32 ± 0.00 cycles / mm and 0.31 ± 0.00 cycles / mm, respectively; and 10% MTFs of the radial proposed method and the rectangular ROI with the homogeneous method are 0.59 ± 0.00 cycles / mm and 0.57 ± 0.00 cycles / mm, respectively.

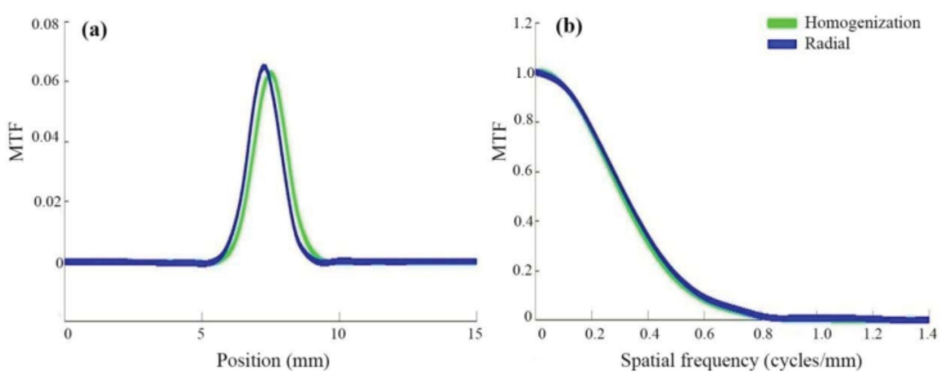

FIGURE 5.Comparisons of LSF curves (left) and MTF curves (right) between the radial ROI and the rectangular ROI with the homogeneous method.

Second, we used a PMMA phantom with 45 degrees rotation corresponding with Anam et al method [11] scanned by Toshiba CT scanner. Then we created radial ROI in 35 to 55 degrees. MTF measurement for different filters was evaluated. The MTF curves obtained using the radial ROI for FC13, FC30, and FC52 filters can be seen in Fig. 6. It can be seen that each filer has different shape of the MTF curve. The 50%MTF values for filters of FC13, FC30 and FC52 are 0.36 ± 0.00, 0.70 ± 0.00, and 0.76 cycles / mm, respectively. The 10%MTF for FC13, FC30, and FC52 filters are 0.67 ± 0.01, 0.95 ± 0.01, and 0.99 ± 0.01cycles / mm, respectively. This shows that the proposed method can differentiate MTF curves for different filters and can be used on different CT scanners because the proposed algorithm yields different spatial resolution depends on the type of CT scanner.

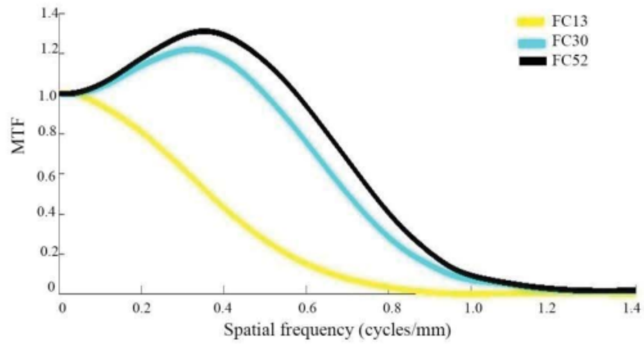

FIGURE 6. The comparison of MTF curves obtained using the radial ROI for FC13, FC30, and FC52 filters.

Next,we will compare MTF curves using rectangular and radial ROI for different filters. It can be shown in Fig. 7. It clearly shows that for all filters, MTF curves obtained using the radial and rectangular ROIcoincidewith each other. 50% and 10% MTF values can be seen in Table 1. The difference of 50% MTF values are seen around 0.01 cycles/mm. The greatest difference of 10% MTF value between the rectangular ROI method and the proposed radial ROI method occur using FC52 filter, 1.07 ± 0.01 cycles/mm and 0.99 ± 0.01 cycles/mm.

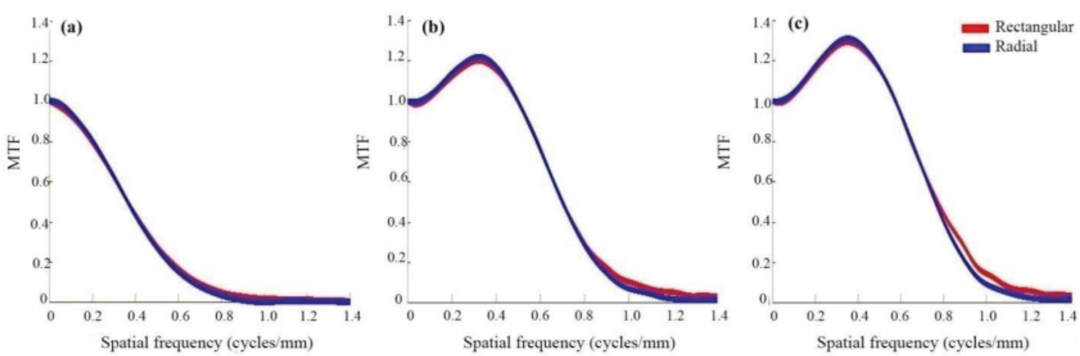

FIGURE 7. The comparisons of MTF curves obtained using the radial and the rectangular ROIs for (a) FC13 (b) FC30 (c) FC52 filters.

TABLE 1. The values of 50% and 10% MTFs for the rectangular and radial ROIs for various filters.

Filter type	Spatial resolution (cycles / mm)			
	Rectangular ROI		Radial ROI	
	50% MTF	10% MTF	50% MTF	10% MTF
FC13	0.37 ± 0.01	0.69 ± 0.01	0.36 ± 0.00	0.67 ± 0.01

FC30	0.70 ± 0.01	1.02 ± 0.01	0.70 ± 0.00	0.95 ± 0.01
FC52	0.77 ± 0.01	1.07 ± 0.01	0.76 ± 0.00	0.99 ± 0.01

CONCLUSION

The automatic method for MTF calculation using the radial ROI on the head PMMA phantom in the standard position has been successfully developed. The MTF 50% values for the rectangular and radial ROIs are 0.30 ± 0.00 cycles/mm and 0.32 ± 0.00 cycles/mm, respectively. The MTF10% values for the rectangular and radial ROIs are 0.58 ± 0.00 cycles/mm and 0.59 ± 0.00 cycles/mm, respectively. This software for automated radial MTF can be used for different CT scanners and different filters.

ACKNOWLEDGEMENTS

This work was funded by the Riset Publikasi Internasional Bereputasi Tinggi (RPIBT), Diponegoro University. Contract Number: 329-116/UN7.6.1/PP/2020).

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