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Optimal Threshold for Automatic Slice Thickness Measurement using Images of the American College of Radiology (ACR) CT Accreditation Phantom

Dewi A. Insiano[1], Choirul Anam[1*], Eko Hidayanto[1], Ariij Naufal[1], Anisa T. Maya[2]

[1]Department of Physics, Faculty of Science and Mathematics, Diponegoro University, Jl. Prof. Soedarto SH, Tembalang, Semarang 50275, Central Java, Indonesia.

[2]Loka Pengamanan Fasilitas Kesehatan (LPFK) Surakarta Jl. Sindoro Raya Jl. Ring Road No. km 1, Mojosongo, Kec. Jebres, Surakarta City 57127, Central Java, Indonesia.

*Corresponding author: anam@fisika.fsm.undip.ac.id

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ABSTRACT

This study aims to find the optimum threshold for the automatic measurement of slice thickness using ACR CT accreditation phantom. The ACR CT accreditation phantom was scanned using Siemens Somatom Perspective CT scanner. The nominal slice thicknesses of 1.5, 3, 5, 6, 7, and 10 mm were investigated. Our automated method was developed to obtain accurate slice thickness values. Several threshold values from 0.10 to 0.50 with increment of 0.05 to find optimum value were investigated. The results obtained from each threshold were then compared with the nominal slice thickness to determine the optimal threshold value. It is found that the optimum threshold in the automatic measurement of slice thickness with nominal slice thickness values from 1.5 to 10.0 mm is from 0.35 to 0.40. Using this range, the different between the nominal slice thickness and measured slice thickness is within 0.5 mm. The optimal threshold for automatic slice thickness measurement has been determined. The optimal threshold would lead to more accurately automated slice thickness measurement.

Keywords: CT scan, slice thickness, ACR CT accreditation phantom, threshold value

I. INTRODUCTION

Computed tomography (CT) is one of the imaging techniques that is able to reveal the internal details of objects in a non-destructive manner, and is the most powerful modality for full-volume inspection of an object because it can provide morphological and physical information on the internal structure of the investigated sample [1,2]. In medical application, CT is used for accurate patient diagnosis [3], due to its ability to produce high-quality three-dimensional images of internal organs, bones, soft tissues, and blood vessels. CT has led to better surgery, cancer diagnosis and treatment, treatment after major injury and trauma, and treatment of stroke and heart conditions [4,5].

CT images provide fully accurate quantitative and qualitative measurements of body composition [6]. Good imaging performance will show that the image quality is sufficient to meet the clinical requirements for examination [7]. To evaluate image quality, there are parameters should be considered such as spatial resolution [8-10], contrast resolution [11], noise [12], and slice thickness [13].

The letter parameter (i.e. slice thickness) can be measured using the American College of Radiology (ACR) CT accreditation [14] or the American Association of Physicists in Medicine (AAPM) CT performance [15] or the Catphan phantoms [16,17]. Healthcare professionals usually measure slice thickness manually, but manual measurement has a weakness. That is, it depends on the subjectivity of the human observer. Therefore, efforts were made to develop an objective measurement method, i.e. automatic method.

Sofiyatun et al. (2021) [18] proposed a method for measuring slice thickness on the AAPM CT performance phantom using MATLAB software. The results indicate that the automatic method produces accurate slice thickness values that are comparable with nominal slice thickness and manual measurements. This system is reported to be more objective and effective than the manual system.

The ACR phantom is one of the most popular phantoms for quality assurance (QA) purposes [19,20]. A free software for automatic slice thickness measurement on the ACR phantom is not available. The automatic method should be able to count number of the inclined ramps that are separated 0.5 mm increments along the longitudinal-axis. The algorithm relies on accurately determining the threshold which still needs to be investigated. Therefore, in this study, we investigated several thresholds used to determine the optimum value.

II. METHODS AND MATERIAL

A. Phantom images

The ACR CT accreditation phantom was scanned with a Siemens Somatom Perspective CT scanner. The phantom was scanned with various slice thicknesses from 1.5 to 10 mm. Scan parameters are tabulated in Table 1.

Table 1. Scan parameters.

Parameters	Value
Acquisition mode	Helical
Tube voltage (kV)	110
Tube current (mA)	100
Pitch	1.0
FOV (mm)	204
Reconstruction filter	Medsternum
Rotation time (s)	1.0
Slice thickness (mm)	1.5, 3, 5, 6, 7, and 10

B. Slice thickness measurement

Figure 1 illustrates all the steps of automatic slice thickness measurement on the ACR phantom. The first step was to open the image using a graphical user interface (GUI) developed the Python programming language. The second step was to determine the orientation angle of the phantom using the bone insert and center of the phantom as a reference. In the case where the phantom was not rotated (rotation angle = 0°), line from center of bone insert and center of phantom has angle 45° with vertical line. The third step was to develop the profile of pixel values across the the inclined ramps to measure the slice thickness of the phantom image. In this case, we constructed two profiles on the left and right inclined ramps, and the result of slice thickness was calculated as the average of the two profiles. The fourth was to normalize the profiles to be easy to remove the noise from the profile. The fifth was to remove noise from the profiles with various threshold value (e.g., 0.2), so that if pixel values in the profile were greater than the threshold will be converted to 1, and otherwise it will be converted to 0. The final step was to automatically count the peak value of the left and right profiles. This automatic measurement has been integrated with IndoQCT software [21].

In this study, threshold values for removing the noise in the profiles were investigated. Threshold was from 0.10 to 0.50 with range of 0.05. Figure 2 shows an

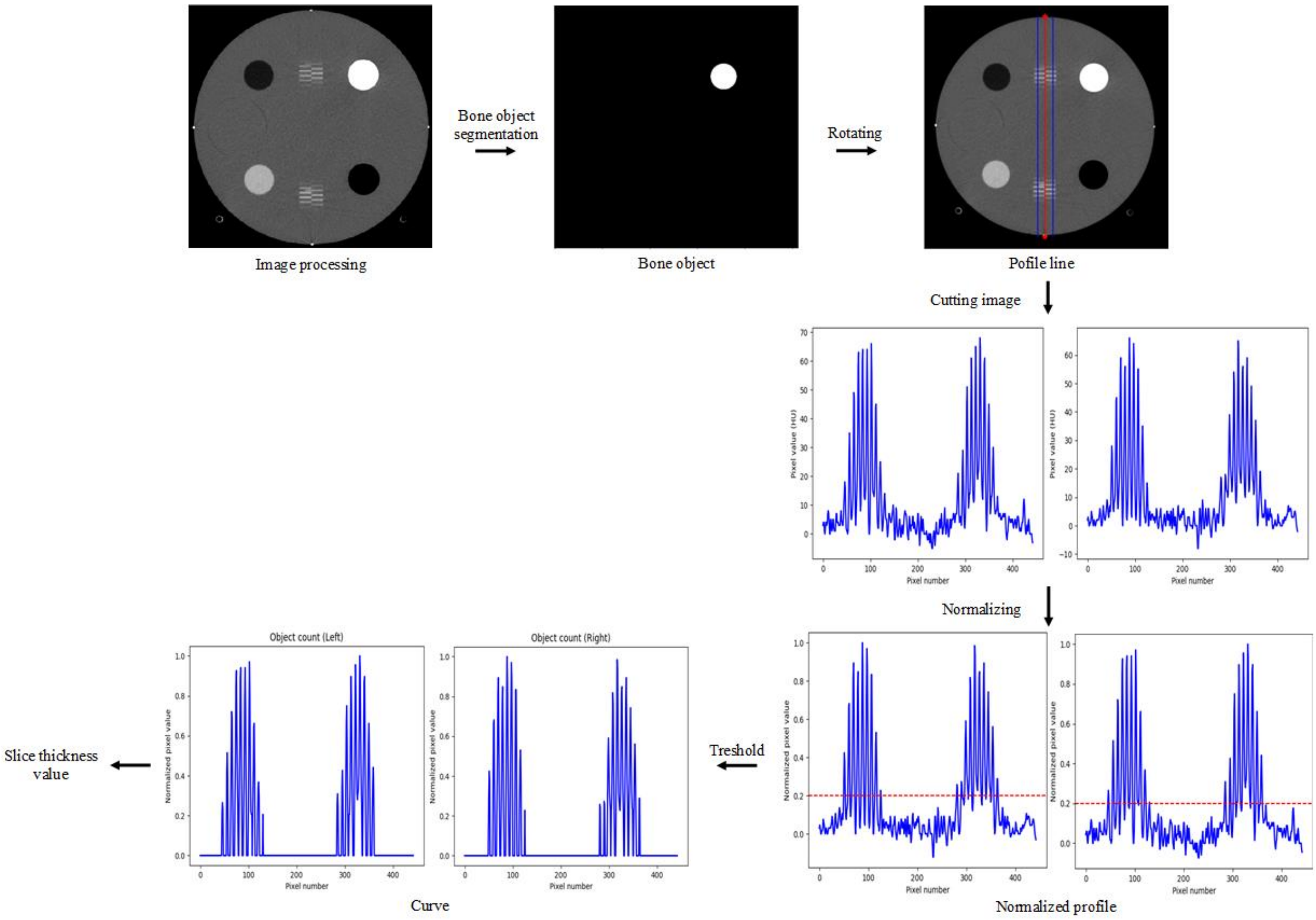

Figure 1. Steps of automatic slice thickness measurement.

example of different results from several threshold values. The number of peaks obtained was different for each threshold value. The best threshold was determined by closest of automatic method with the nominal slice thickness.

III.RESULTS AND DISCUSSION

The results of automatic slice thickness measurements with various threshold values for nominal slice thicknesses from 1.5 to 10.0 mm are tabulated in Table 2. The slice thickness from the left, right, and average inclined ramps are included. The differences between average slice thickness from automatic measurements and nominal slice thickness are calculated. It is found that 0.5 mm slice difference is obtained for threshold values from 0.35 to 0.40.

This study aims to find the optimal threshold for the automatic measurement of slice thickness on the ACR phantom. We use several nominal slice thickness values from 1.5 to 10.0 mm by varying the threshold value in the IndoQCT software.

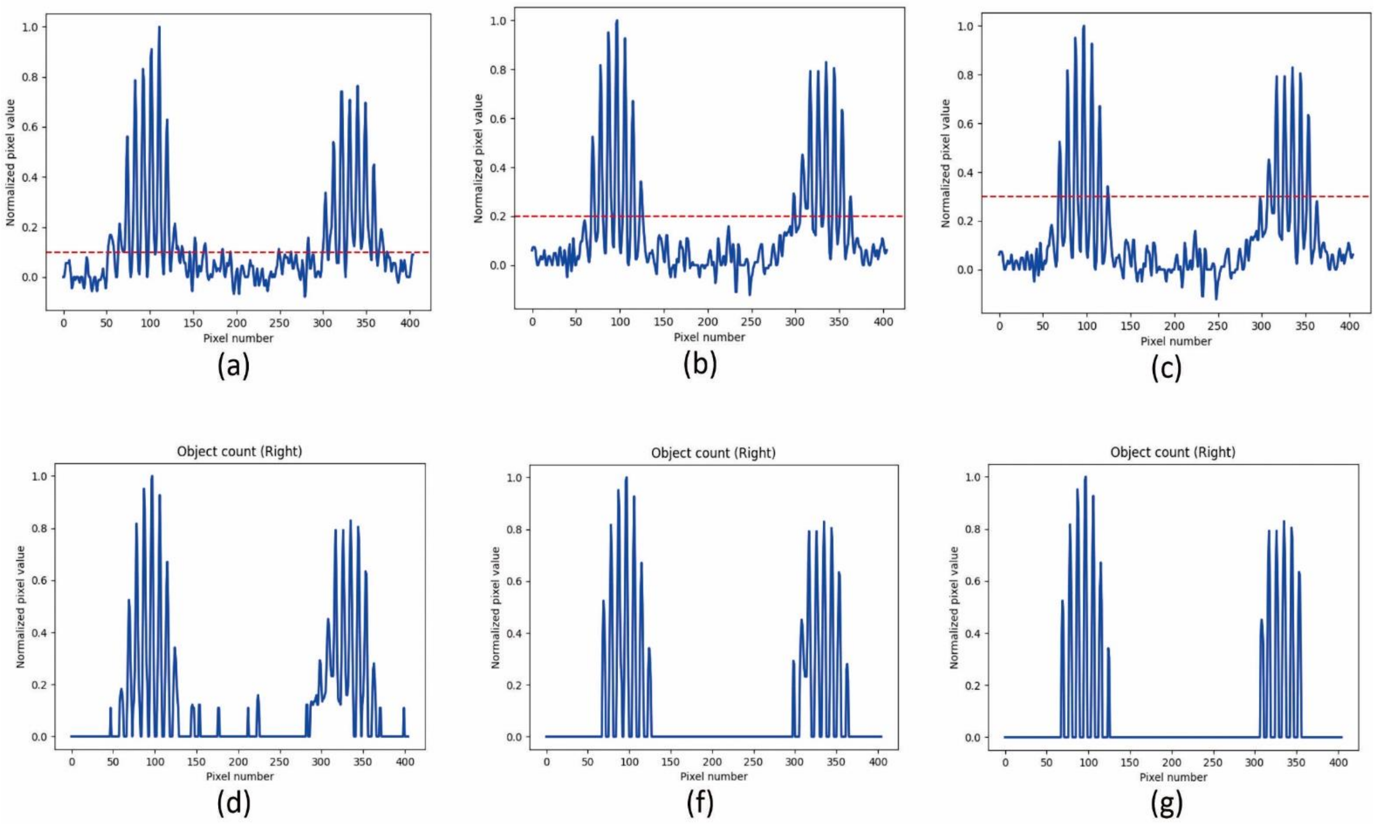

Figure 2. Profiles for determining the slice thickness with three different threshold values of (a) 0.1, (b) 0.2, and (c) 0.3, with the respective results from (d) to (g).

Table 2. The results of automatic slice thickness measurements with various threshold values for nominal slice thicknesses from 1.5 to 10.0 mm.

Nominal slice thickness (mm)	Noise* (HU)	Threshold value	Thickness (left) (mm)	Thickness (right) (mm)	Average thickness (mm)	Difference (mm)
1.5	8.2	0.10	6.00	4.00	5.00	3.50
		0.15	3.00	3.00	3.00	1.50
		0.20	2.50	3.00	2.80	1.20
		0.25	2.50	2.00	2.20	0.80
		0.30	2.50	2.00	2.20	0.80
		0.35	2.50	1.50	2.00	0.50
		0.40	2.50	1.50	2.00	0.50
		0.45	2.50	1.50	2.00	0.50
		0.50	2.00	1.50	1.80	0.20
3.0	5.5	0.10	7.50	6.50	7.00	4.00
		0.15	5.50	5.50	5.50	2.50
		0.20	4.00	4.50	4.20	1.20
		0.25	4.00	4.50	4.20	1.20
		0.30	3.50	3.50	3.50	0.50

		0.35	3.50	3.50	3.50	0.50
		0.40	3.50	3.00	3.20	0.20
		0.45	3.50	2.50	3.00	0.00
		0.50	3.50	2.50	3.00	0.00
5.0	4.88	0.10	10.50	9.00	9.80	4.80
		0.15	7.50	8.00	7.80	2.80
		0.20	5.50	6.00	5.80	0.80
		0.25	5.50	5.00	5.20	0.20
		0.30	5.50	4.50	5.00	0.00
		0.35	5.50	4.50	5.00	0.00
		0.40	5.00	4.50	4.80	0.20
		0.45	4.50	4.00	4.20	0.80
		0.50	4.00	4.00	4.00	1.00
6.0	4.09	0.10	13.50	14.00	13.80	7.80
		0.15	9.00	8.50	8.80	2.80
		0.20	7.00	7.00	7.00	1.00
		0.25	6.00	7.00	6.50	0.50
		0.30	6.00	6.00	6.00	0.00
		0.35	5.50	5.50	5.50	0.50
		0.40	5.50	5.50	5.50	0.50
		0.45	5.00	5.50	5.20	0.80
		0.50	5.00	5.00	5.00	1.00
7.0	3.36	0.10	17.00	12.50	14.80	7.80
		0.15	10.00	9.50	9.80	2.80
		0.20	9.50	9.00	9.20	2.20
		0.25	8.50	8.50	8.50	1.50
		0.30	8.00	7.00	7.50	0.50
		0.35	7.50	7.00	7.20	0.20
		0.40	7.00	7.00	7.00	0.00
		0.45	6.00	6.50	6.20	0.80
		0.50	6.00	6.50	6.20	0.80
10.0	2.63	0.10	21.00	17.50	19.20	9.20
		0.15	16.00	14.00	15.00	5.00
		0.20	12.50	11.50	12.00	2.00
		0.25	11.00	11.00	11.00	1.00
		0.30	10.50	10.50	10.50	0.50
		0.35	10.50	10.50	10.50	0.50
		0.40	10.00	9.50	9.80	0.20
		0.45	9.50	9.50	9.50	0.50
		0.50	9.00	9.00	9.00	1.00

* Noise was measured by finding the standard deviation from placing an ROI with a diameter of 40 pixels in the center of the phantom.

If the threshold value is too small, then noise will be detected as the inclined ramps so that the result of the slice thickness measurement will increase. Conversely, if the threshold value is too high, then the inclined ramps for measuring slice thickness will be considered as noise, so the measured slice thickness will decrease. Therefore, an optimal threshold value is required so that the measured slice thickness value is accurate. In this study, we investigate threshold values from 0.10 to 0.50. It is noted that these threshold values were only used for the profile has been normalized.

It was obtained that the optimal value for each nominal slice thickness is different. For example, for a small nominal slice thickness (i.e. 1.5 mm), the threshold value resulting in a small difference between the nominal slice thickness and the measured slice thickness is from 0.3 to 0.5. Whereas for a large nominal slice thickness (i.e. 10.0 mm), the threshold value resulting in the small difference between the nominal slice thickness and the measured slice thickness is from 0.3 to 0.45. If all nominal slices are combined, a 0.5-mm slice difference was obtained for threshold values from 0.35 to 0.40.

It appears that the thinner the slice thickness will produce greater image noise [22]. This is because the thinner the slice thickness, number of photons detected by the detector for image reconstruction is fewer and resulting in a larger quantum noise [23]. When the noise increases, the threshold used to remove noise should be larger. However, if threshold value is too large, the ramp's pixel value will also be detected as noise, so that the slice thickness measurement becomes less accurate. In general, for a nominal slice thickness between 1.5 and 10.00 mm, a threshold value between 0.35 and 0.40 seems to be good.

However, it should be noted that these results are only obtained on images reconstructed using the filtered back-projection (FBP) algorithm and only with one type of filter [24]. If the image is reconstructed with another algorithm, such as iterative reconstruction (IR) or deep learning (DL), or reconstructed with a different filter, it may need a different threshold value to accurately measure slice thickness value. A study of determining threshold values for several filter types and several image reconstruction algorithms will be carried out in the further research.

It should also be noted that in this study, other input parameters such as voltage, tube current, rotation time and others are set constant. The optimum threshold value may change for other exposure factors.

In certain cases, there may be some disturbing artifacts in the image [25,26]. To overcome this, it is necessary to implement appropriate efforts so that the threshold value

Accurate determination of slice thickness will greatly assist medical personnel in carrying out routine quality control. Automated measurement of other quality parameters, such as spatial resolution, contrast resolution, and noise uniformity also needs to be done to help medical personnel in hospitals.

IV. CONCLUSION

Optimum threshold for the automatic measurement of slice thickness using the ACR phantom has been investigated. The results showed that the optimum threshold in the automatic measurement of slice thickness with nominal slice thickness values from 1.5 to 10.0 mm is from 0.35 to 0.40. Using this range of threshold, the different between the nominal slice thickness and measured slice thickness is within 0.5 mm. However, implementation of other input parameters, reconstruction filters, and reconstruction algorithm need to be investigated further.

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