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An evaluation of automated measurement of slice sensitivity profile of computed tomography image: field of view variations

Elvira Rizqi Widyanti[1], Choirul Anam[1], Eko Hidayanto[1], Ariij Naufal[1], Mohammad Haekal[2]
[1]Department of Physics, Faculty of Sciences and Mathematics, Diponegoro University, Semarang, Indonesia
[2]Department of Physics, Faculty of Science and Data Analytics, Institut Teknologi Sepuluh Nopember, Kampus ITS Sukolilo, Surabaya, Indonesia

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ABSTRACT

This study aims to evaluate the automated measurement of slice sensitivity profile (SSP) on the American Association of Physicists in Medicine (AAPM) computed tomography (CT) performance phantom for variations of slice thickness and field of view (FOV). The AAPM CT performance phantom was scanned using a Philips MRC 880 CT Scanner for variations of slice thickness and FOV. The slice thickness values were 1, 3, and 5 mm. The FOV values were 240, 300, 340, 400, and 440 mm. The automated SSPs and their full-width at half maximums (FWHMs) were automatically measured from the middle stair object of the phantom. To validate the automated measurement results, the FWHM values of SSPs obtained were compared to those from manual measurements. The differences between FWHMs from automated measurements and set slice thicknesses are less than 0.3 mm, while the differences between FWHMs from automated and manual measurements are less than 0.2 mm. The results from automated measurements are closer to the set slice thickness than those from manual measurements. This automated SSP measurement provides high accuracy and precision for both the slice thickness and the FOV variations.

Corresponding Author:

Choirul Anam
Department of Physics, Faculty of Sciences and Mathematics, Diponegoro University
Semarang, Central Java, Indonesia
Email: anam@fisika.fsm.undip.ac.id

1. INTRODUCTION

The first computed tomography (CT) examination was performed to detect a suspected tumor in the woman's brain [1]. It produces an image with a matrix of 80×80 pixels with a scan time of approximately 4.5 minutes for one cross section's image with a thickness of 13 mm [1]. Nowadays, it has been widely stated that CT is a remarkable radiological modality that allows us to excellently produce 3D images of patients [2]. Multi-slice CT (MSCT) is a part of the most advanced technology which comes with more advantages over its conventional versions. Some of the advantages include thinner slice thickness, higher spatial resolution, and shorter scanning time [3].

Slice thickness is one of the important parameters that determine image resolution among many parameters considered in a CT scan examination [4]. In the past, the slice thickness values were limited to the range of 5 to 10 mm [5], which could only show low-resolution images. Currently, slice thickness has been reduced to less than 1 mm [6]. Improved CT technology has also enabled the radiographer to capture hundreds to over thousands of images of the body in one single examination by helical MSCT technology, which results in thinner slice thickness [5]. The thinner slice thickness can provide a more visibly-detailed structure of the body scanned and leads to an increase of the image spatial resolution [2], [7].

The measurement of image resolution should be performed not only in-plane or in *xy* directions, but also in the z-direction. The image resolution along the *z*-axis is called a slice sensitivity profile (SSP) or longitudinal resolution [8]. The full-width at half maximum (FWHM) of SSP is usually used for evaluating the slice thickness [9], [10]. The SSP is a parameter that could be identified to evaluate the conditions of the CT system in quality control (QC) program. The SSP measurement can be performed using several types of phantoms [4]. The CatPhan and American College of Radiology (ACR) phantoms are commercial phantoms that are available for SSP measurements [11]-[14]. The measurement of SSP in the CatPhan phantom can be done manually by measuring the length of line of four wire ramps and multiplying it with tangent of 23°. Meanwhile, the measurement of SSP in the ACR phantom is performed manually by counting the number of discrete wires visible displayed on the axial images of the phantom [13]. The SSP can also be measured using the American Association of Physicists in Medicine (AAPM) CT performance phantom (CIRS, Virginia, USA) [15]. The SSP is measured at the stairs object within the phantom. The thickness of the stairs object is usually obtained using the caliper on the console [16].

The SSP measurements are usually carried out manually by the medical staff. Although the manual measurement gives accurate results, the process is time-consuming. An automated SSP measurement was developed by analyzing the stairs images and determining its FWHM to overcome this problem. Sofiyatun *et al.* [17] proposed an algorithm for automated SSP measurement from AAPM CT performance phantom regardless of the angle of the phantom [17]. The automatic measurement provided more effective, objective, and practical results. The algorithm was evaluated by Lasiyah *et al.* [18] for variations of filter and distance from the iso-center, and evaluated by Widyanti *et al.* [19] for variation of noise. The algorithm was also refined by Ximenes *et al.* [20]. However, the previous automated SSP measurement was only implemented at one field of view (FOV). Therefore, this study aims to implement and evaluate the software for automated SSP measurement using AAPM CT performance phantom at various FOV values. The results from automated measurements will be compared with those from manual measurements.

2. METHOD

The study was conducted at the Rumah Sakit Nasional Diponegoro (RSND). Figure 1 shows the scanner we used with the test phantom and its sample axial image. The CT scanner used was Philips (MRC 880) 128 slice as displayed in Figure 1(a). The part of the AAPM CT performance phantom (Model 610, Part No 610-04, CIRS, Virginia, USA) for measuring SSP was made of aluminum with size of 0.635 mm × 25.4 mm. Three aluminum plates were placed within the phantom. Those plates were positioned in the middle and parallel to each other, with an angle of 45º to the phantom position as can be seen in Figure 1(b). An example image of the part of the AAPM CT performance phantom is shown in Figure 1(c). In this study, three different slice thickness values and five different FOVs values were set using the acquisition parameters according to Table 1 and Table 2. All images were saved and processed in the digital imaging and communications in medicine (DICOM) format.

(a) (b) (c)

Figure 1. Phantom positioning on CT and its image sample; (a) Philips (MRC 880) 128 slice CT scanner, (b) AAPM CT performance phantom, and (c) example of phantom image

Table 1. Acquisition parameters for slice thickness variations

Acquisition parameter	Unit	Quantity
Tube voltage	kV	120
Tube current	mA	200
Mode	-	Helical
Pitch	-	0.984
Field of view (FOV)	mm	260
Rotation time	s	1
Filter reconstruction	-	Lung
Slice thickness	mm	1, 3, and 5

Table 2. Acquisition parameters for field of view (FOV) variations

Acquisition parameter	Unit	Quantity
Tube voltage	kV	120
Tube current	mA	200
Mode	-	Helical
Pitch	-	0.984
Rotation time	s	1
Filter reconstruction	-	Lung
Slice thickness	mm	5
Field of view (FOV)	mm	240, 300, 340, 400, and 440

2.1. Manual measurement

The manual measurement of the width of SSP was performed by using IndoQCT [21] to validate the automated measurement results. Figure 2 shows the graphical user interface (GUI) of IndoQCT to measure the image's slice thickness. After opening the IndoQCT, the manual measurement of slice thickness option was selected. The image was zoomed-in to accurately measure the width of SSP as shown in Figure 2.

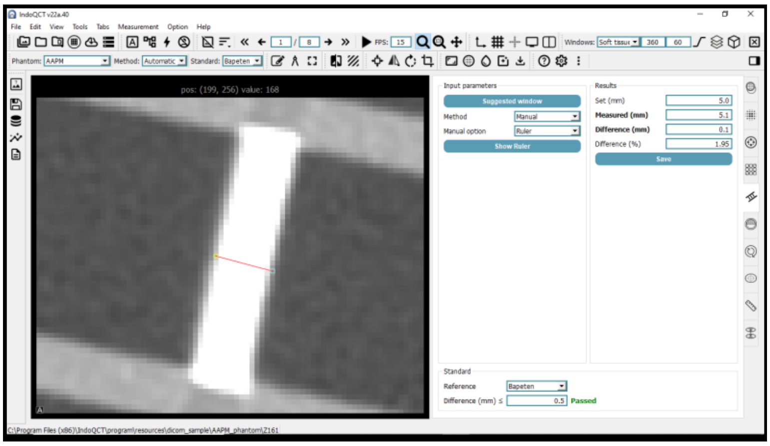
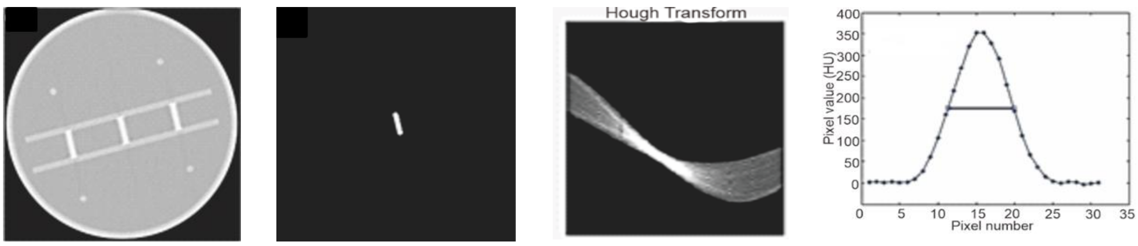


Figure 2. The screen display to manually measure image's slice thickness using IndoQCT

2.2. Automated calculation

The automated SSP measurement was previously introduced [17] and consisted many steps as displayed in Figure 3. The original image of stair object as shown in Figure 3(a) was segmented. The middle stair object was taken and other stairs were erased as shown in Figure 3(b). The angle of the stair object was automatically determined by using Hough transformation as shown in Figure 3(c). By using the center information of the middle stair, the stair object in the original images was cropped and then rotated based on the angle information. Subsequently, the pixel profiles across the stair object were built and then averaged. This curve represented the SSP. Finally, the FWHM of the SSP was automatically determined as shown in Figure 3(d).



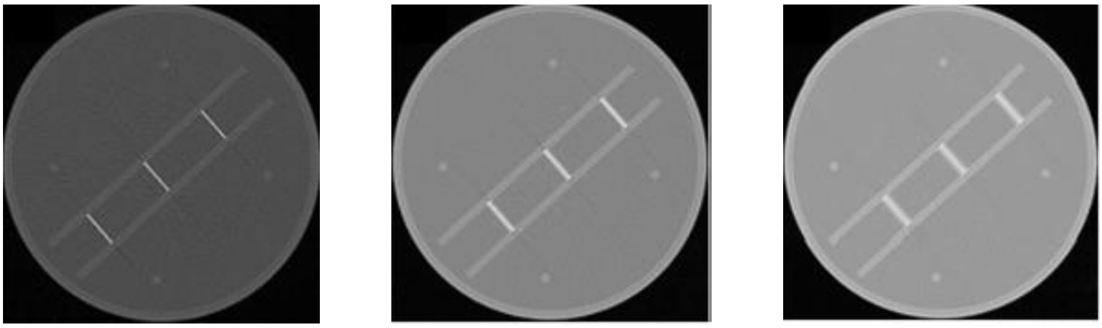
(a) (b) (c) (d)

Figure 3. Image processing for automated measurement, (a) the original CT scan image of the stairs object, (b) image showing a middle of stair was segmented, (c) image showing the result of Hough transformation for automatically the angle of the stair object, and (d) the slice sensitivity profile and its FWHM was automatically determined

3. RESULTS AND DISCUSSION

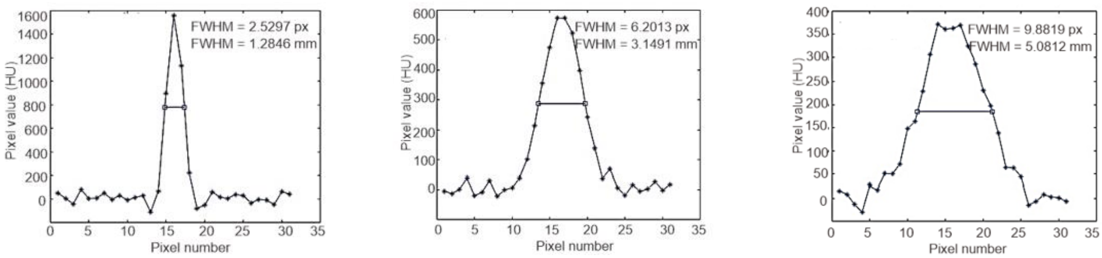
3.1. Slice thickness variation

Figure 4 shows the phantom images for the slice thickness variations of 1 in Figure 4(a), 3 in Figure 4(b), and 5 mm in Figure 4(c). The SSPs and their FWHM values are shown in Figure 5 with slice thicknesses of 1 in Figure 5(a), 3 in Figure 5(b), and 5 mm in Figure 5(c). The *x*-axis in SSP of Figure 5 represents the pixel number in the unit of pixels and the *y*-axis represents the pixel value in Hounsfield unit (HU). However, the FWHM values are represented in both pixels and mm units. Table 3 shows the average and the standard deviations of full-width at half maximums (FWHMs) obtained from manual and automated measurements. It shows that the results of automated measurements were closer to the set slice thickness values (i.e. 1, 3, and 5 mm) compared to those of manual measurement. The difference between the automated and manual measurements was less than 10% or less than 0.5 mm.



(a) (b) (c)

Figure 4. Phantom images for the slice thickness variations of (a) 1 mm, (b) 3 mm, and (c) 5 mm



(a) (b) (c)

Figure 5. Slice sensitivity profiles and their FWHM values for the slice thickness values of (a) 1 mm, (b) 3 mm, and (c) 5 mm

Table 3. FWHM values of automated and manual measurements for the slice thickness variation

Slice thickness (mm)	FWHM (mm)		Discrepancy (%)
	Automated measurement	Manual measurement	
1	1.3 ± 0.1	1.4 ± 0.1	7.1
3	3.2 ± 0.1	3.4 ± 0.2	5.9
5	5.3 ± 0.1	5.1 ± 0.1	3.8

3.2. Field of view variation

Figure 6 shows the phantom images for the FOVs of 240 in Figure 6(a), 300 in Figure 6(b), 340 in Figure 6(c), 400 in Figure 6(d), and 440 mm in Figure 6(e). The SSPs and their FWHM values are shown in Figure 7 with FOVs of 240 in Figure 7(a), 300 in Figure 7(b), 340 in Figure 7(c), 400 in Figure 7(d), and 440 mm in Figure 7(e). In the FOV variation, the slice thickness value was set constant at 5 mm. Table 4 indicates the FWHM values from the automated and manual measurements. The automated measurement was able to accurately obtain the SSP and FWHM for FOV variation. Moreover, the automated measurement results were closer to the set slice thickness value compared to those of manual measurements. The difference between the automatic and manual measurement results was less than 10% or less than 0.5 mm for FOV variation.

Automated SSP measurements using AAPM CT performance phantom has been previously developed [17]. The algorithm was only specific to the AAPM CT performance phantom, while algorithm for other phantoms could be found in the literature [11]. This automated SSP measurement software was developed to overcome the disadvantages of the conventional measurement method, which was measured using a caliper. The conventional method tends to be time-consuming and provides subjective measurement results depending on the analyzer conditions [22]. Therefore, the use of automated calculation software could reduce the analyzing time and could provide more objective results [17].

The automated measurement method displayed the SSP and its FWHM value, both in pixels and mm. An image in DICOM format which provided pixel size information was required to perform the measurement. This algorithm was only applied in DICOM format, since the DICOM consists of two important data sets, i.e. image data set and a header which provides information on the image needed for the analysis such as the matrix size and pixel size, which was very helpful on the analysis process [23]. Implementation of this algorithm in other than DICOM format should be accompanied by pixel size information.

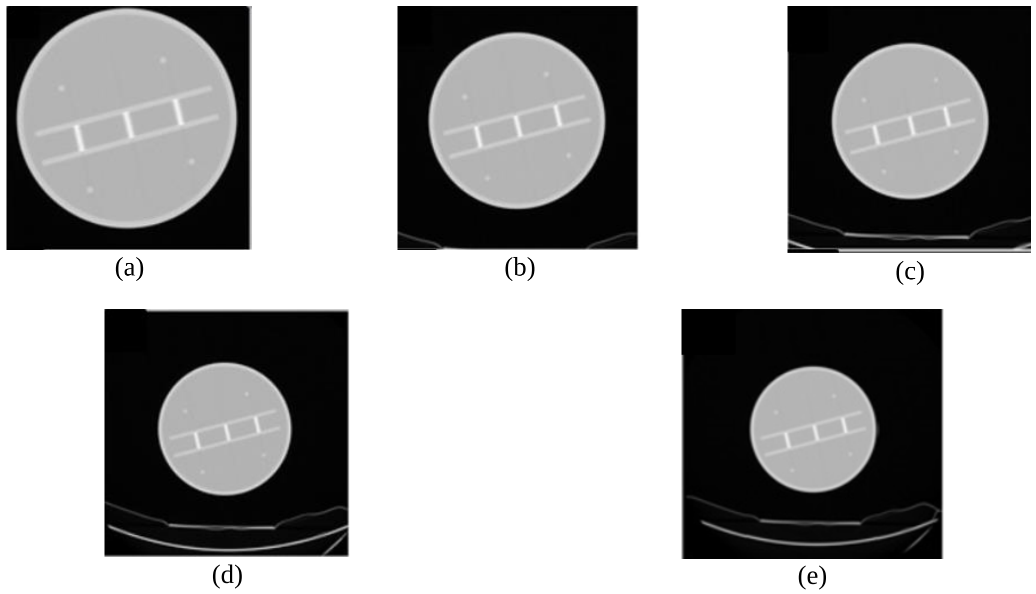


Figure 6. Phantom images with various FOVs of (a) 240 mm, (b) 300 mm, (c) 340 mm, (d) 400 mm, and (e) 440 mm

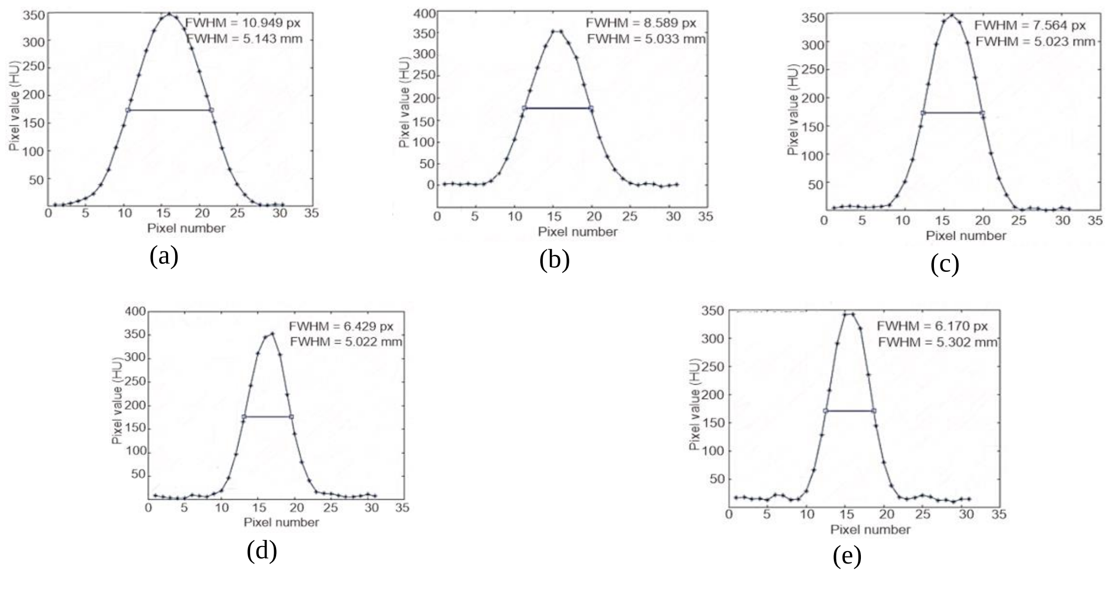


Figure 7. The SSPs and their FWHM values for various FOVs of (a) 240 mm, (b) 300 mm, (c) 340 mm, (d) 400 mm, and (e) 440 mm

Table 4. FWHM values of automated and manual measurements for various FOVs

FOV (mm)	Slice thickness (mm)		Discrepancy (%)
	Automated measurement	Manual Measurement	
240	5.1 ± 0.0	5.2 ± 0.2	1.9
300	5.0 ± 0.1	5.2 ± 0.2	3.8
340	5.0 ± 0.1	5.1 ± 0.1	2.0
400	5.1 ± 0.1	5.2 ± 0.2	1.9
440	5.3 ± 0.1	5.4 ± 0.2	1.9

The automated measurement initially detected the phantom angle using Hough transformation. Thus, no matter which angle the phantom was oriented, this algorithm was able to accurately measure the SSP [17]. However, evaluation of the algorithm on other parameters, such as field of view (FOV) has not been carried out. The evaluation of the algorithm on various slice thicknesses and FOVs are necessary since the slice thickness and FOV in a clinical setting are usually implemented in a wide range [24]. Based on this, an evaluation of the algorithm for automated SSP measurement from AAPM performance phantom for various FOVs has been evaluated in the current study.

The results obtained for the FOV variation show that this algorithm was accurate. The differences from the set slice thickness were less than 0.5 mm. Thus, this indicates that this algorithm will still provide accurate results regardless of the FOV values used as long as it is within the range of 240 mm to 440 mm which would make it easier for users to perform phantom scanning. However, an evaluation on FOV less than 240 mm or more than 440 mm still needs to be carried out in the further study.

It is noted that the automated SSP measurement provides more objective results because it does not depend on the experience and expertise of the medical personnel involved. This automated measurement method is also very easy to implement since the user only press one button to perform the automated measurement. The results of automated results tend to be closer to the set slice thickness than those from manual measurements.

In this study, measurement of the SSP was performed only on the middle stair object. It is assumed that the SSP measurement on three stairs objects may give more robust results. Therefore, it is necessary to carry out further studies on this issue. The development of automatic measurements on AAPM CT performance phantom for all measurement parameters other than SSP (such as noise [25], low-contrast detectability [21], mechanical alignment, beam hardening, spatial resolution [26], HU linearity [27], and so on) may give great benefit to medical physicists in implementing quality control programs. Nevertheless, it still poses a challenge for future studies.

4. CONCLUSION

An algorithm for automated SSP measurements on the AAPM CT performance phantom for various slice thicknesses and FOVs was validated. Automated and manual measurements provided results that were close to the set slice thicknesses. The difference in FWHMs from automated measurements and set slice thicknesses for variations of slice thicknesses and FOVs were less than 0.3 mm. Meanwhile, the difference of FWHMs from automated and manual measurements for variations of slice thicknesses and FOVs were less than 0.2 mm. Therefore, the automated SSP measurement is proven to be accurate. The automated method is more objective, effective, and practical as part of a quality control program.

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BIOGRAPHIES OF AUTHORS

Elvira Rizqi Widyanti is a student of the physics master's program at Diponegoro University. She underwent her bachelor's education at Semarang State University. She can be contacted at elvirarizqi.2019@fisika.fsm.undip.ac.id.

Dr. Choirul Anam completed his Ph.D in Physics Department, Bandung Institute of Technology (ITB). He received Master degree from University of Indonesia (UI) and the B.Sc degree from Diponegoro University (UNDIP). He is currently working as a Lecturer and Researcher at the UNDIP. His research interests are medical image processing and dosimetry for diagnostic radiology, particularly in CT. He has authored and co-authored over 150 papers. One of his papers published in the Journal of Applied Clinical Medical Physics (JACMP) had been awarded as the Best Medical Imaging Physics Article in 2016. He was also recognised as an Outstanding Reviewer for the Physics in Medicine and Biology (PMB) in 2018 and for the Biomedical Physics and Engineering Express (BPEX) in 2019. He is developer of two software, i.e. IndoseCT (for calculating and managing radiation dose of CT) and IndoQCT (for measuring CT image quality). He can be contacted at email: anam@fisika.fsm.undip.ac.id.

Dr. Eng. Eko Hidayanto is a lecturer in radiation physics at Diponegoro University. His expertise is radiation protection and medical materials. He can be contacted at email: ekohidayanto@fisika.fsm.undip.ac.id.

Ariij Naufal is a graduate student of the physics master's program at Diponegoro University. He is the developer of IndoQCT. He can be contacted by email: ariij.2019@fisika.fsm.undip.ac.id.

Ph.D. Mohammad Haekal is a lecturer at Department of Physics, Institut Teknologi Sepuluh Nopember. He completed his Ph.D. at Kyushu University, Japan. He can be contacted at haekal@its.ac.id.