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# An Approach for Automation of CT Number Linearity Measurement on the TOS Phantom Image

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**ABSTRACT**

Assessment of the computed tomography (CT) number linearity is an important part in the Quality Control (QC) procedures of CT images. An automated method is needed for simplify the measurement process of this parameter. This study aims to develop an automated method for measuring CT number linearity on the TOS phantom images scanned with Toshiba Aquilion Lightning CT scanner with variations of tube current, tube voltage, and slice thickness. The automation began with segmenting the phantom object with a threshold of - 200 Hounsfield units (HU). Then, the centroid was determined for the phantom mask. The air object inside the phantom and its centroid were segmented utilizing a threshold of - 900 HU. By performing a simple rotation operation between the two obtained centroids (i.e., phantom and air centroids), the central coordinates of Delrin, acrylic, nylon, and polypropylene materials were determined. CT number linearity and its coefficient of determination (R2) were calculated. The proposed method was evaluated with datasets scanned from variations of tube current, tube voltage, and slice thickness. The automated CT number linearity measurements were successfully developed. The CT number linearity showed acceptable results for all variations (R2>0.99). Moreover, no significant changes in CT numbers of all materials compared to the standard values were noticed.

**Keywords**: CT number, CT number linearity, Noise

## I. INTRODUCTION

Assessment of computed tomography (CT) number linearity is an important part in routine quality control (QC) procedures [1]. This is because CT number linearity straightforwardly indicates the accuracy of CT numbers for different materials with various densities [2,3]. A dedicated phantom equipped with materials of different densities is needed to asses CT number linearity. The sophisticated available phantoms, such as the American Association of Physicists in Medicine (AAPM) CT Performance phantom [4], the American College of Radiology (ACR) CT Accreditation phantom [5], and the Catphan phantom [6] are notable examples.

From axial images of those phantom, region of interests (ROIs) are drawn on different materials to extract their CT numbers [7]. The CT numbers of various materials should well correlate with their densities. Regularly, this assessment includes the utilization a specific software to obtain the results. Because of its tedious and subjective nature, there is an increasing need for automated method for this task. To date, several softwares have been developed to measure CT number linearity on some available phantoms [5,8], however there is no automated method developed for measuring CT number linearity for the TOS phantom.

The already developed software restricted to solely working on a single phantom type. For our QC routine, we use a Toshiba CT scanner with its own built-in phantom, the TOS phantom [7]. Therefore, an availability software of automated assessment of CT number linearity on the TOS phantom is needed. Based on this problem, this study aims to develop an approach for automated method to measure CT number linearity on TOS phantom image and evaluate it with variation of tube current, tube voltage, and slice thickness.

## II. METHODS AND MATERIAL

### a. Measurement of CT Number Linearity on TOS Phantom

A multi-pin module (consist of five materials with different densities) was used for measuring CT number linearity. Each material in the module has different diameter as shown in Figure 1. The five materials are Air, Delrin™, Acrylic, Nylon, and Polypropylene [7]. The five materials are located in the Water as its background.

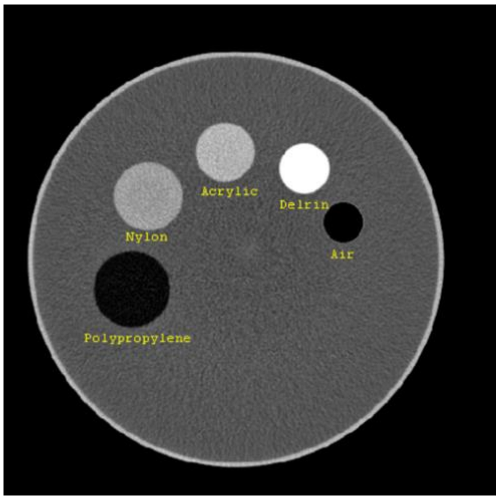


**Figure 1**. Axial image of the TOS phantom with five different material inserts.

Figure 2 shows an overview of automated CT number linearity measurement on the TOS phantom. The process was started by opening the image of the phantom (Figure 2a). Then, the phantom was segmented with threshold of - 200 Hounsfield units (HU) to produce a phantom mask. The centroid of phantom mask was then determined (Figure 2b) [9]. Following this, the air object inside the phantom was segmented with a threshold of - 900 HU, producing an air mask and its centroid (Figure 2c). By performing a simple rotation operation between the two obtained centroids (phantom and air centroids), i.e., utilizing angles of 34°, 77°, 125°, and 177° in the counterclockwise direction, central coordinates of Delrin, Acrylic, Nylon, and Polypropylene materials were determined (Figure 2d). In order to determine the average CT number for each material, circle-shaped ROIs were assigned to these six centroid coordinates (Figure 2e). The CT number linearity was determined by graph of the CT number of each material against its respective density. The coefficient of regression ($R^2$) (Figure 2f) was determined for describing the linearity. The proposed method was integrated as part of features of IndoQCT software [10].

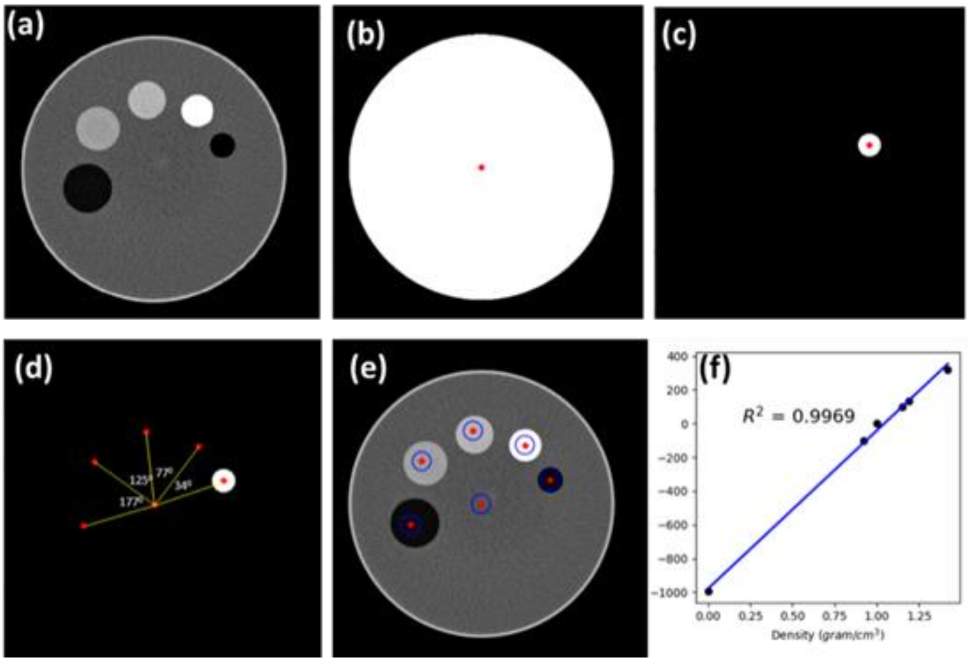


**Figure 2**. Steps of automatic CT number linearity measurement on the TOS phantom. (a) original axial image; (b) phantom mask with its centroid; (c) air mask inside the phantom with its centroid; (d) Rotational operations between the phantom centroid and water centroid to determine other materials centroid; (e) ROIs placement based on determined coordinates; and (f) graph between CT numbers and their respective densities to obtain the linearity.

**Table 1**. Setting parameter CT Scanner.

| No | Parameter | Tube current variation | Tube voltage variation | Slice thickness variation |
|---|---|---|---|---|
| 1 | FOV (mm) | 350 | 350 | 350 |
| 2 | Scan mode | Helical | Helical | Helical |
| 3 | Pitch | 0.6 | 0.6 | 0.6 |
| 4 | Time rotation (s) | 0.75 | 0.75 | 0.75 |
| 5 | Filter | High resolution | High resolution | High resolution |
| 6 | Tube voltage (kVp) | 120 | 80, 100, 120, 135 | 120 |
| 7 | Tube current (mA) | 50, 100, 150, 200, 250, 300 | 50 | 200 |
| 8 | Slice thickness (mm) | 5 | 1 | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 |

### b. Acquisition of the Dataset

The phantom was scanned by the Toshiba Aquilion Lightning CT scanner with helical mode, utilizing a pitch of 0.688, field of view (FOV) of 390 mm, tube voltage of 120 kV, and a slice thickness of 5 mm. To evaluate the algorithm's performance, we tested image of phantom scanned with 3 variations: tube current, tube voltage, and slice thickness. The tube current was set at levels of 50, 100, 150, 200, 250, and 300 mA. The tube voltage was set at levels of 80,100, 120, and 135 kV. The slice thickness was set at levels 1, 2, 3, 4, and 5 mm. Complete scan parameter can be seen at Table 1.

## III.RESULTS AND DISCUSSION

Figure 3 shows the results of automatic placement of ROIs of different materials on the variation of tube current. The developed software can detect each target object and place the ROIs within the objects correctly. This proves the robustness of the automatic segmentation of the objects within the TOS phantom. However, it can be seen that each ROI is not exactly in the center of every object. This is because each material has a different size, so that their centroids are at different locations from the iso-center.

The results of CT number of each object and the CT number linearity evaluation are tabulated in Table 2. The measured CT numbers in all materials did not significantly different from the reference CT numbers, with the Delrin showing the greatest difference up to 22.5 HU. It is found that CT number of air material increases with the increase of tube current. In all tube currents, Results of CT number linearity show comparable outcomes, with values of 0.9969 and 0.9970. It is important to note that these outcomes are still within the tolerance limit set by regulatory body in Indonesia ($R^2 > 0.99$) [11].

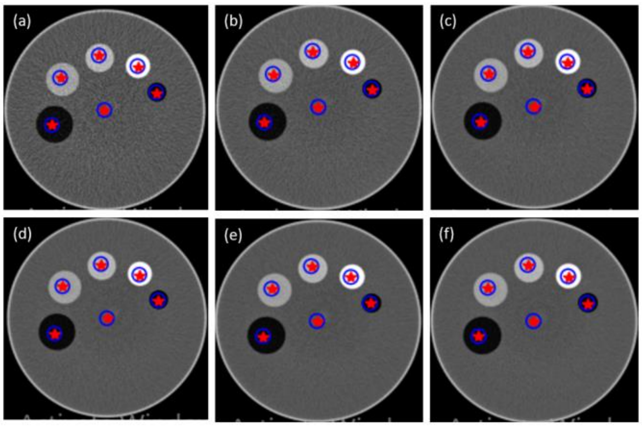


**Figure 3**. Results of automatic placement of ROIs on images of various tube currents. (a) 50 mA, (b) 100 mA, (c) 150 mA, (d) 200 mA, (e) 250 mA, and (f) 300 mA.

Figure 4 shows the results of automatic placement of ROIs of different materials on the variation of tube voltage. Again, the developed software can detect each target object and place the ROIs within the objects correctly, although the ROIs are not exactly in the center of every object. The results of CT number of each object and the CT number linearity evaluation for tube voltage variation are tabulated in Table 3. The results show that water and air materials provide greater CT number shifting compared to other materials such as Polypropylene, Aylon, Acrylic and Delrin [12]. CT number linearity for tube voltage variation is within the tolerance limit [11].

**Table 2**. Result of CT number of each object and CT number linearity measured using IndoQCT for tube current variation.

| | Material | Density (gr/cm³) | CT Number (HU) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Reference | 50 mA | 100 mA | 150 mA | 200 mA | 250 mA | 300 mA |
| 1 | **Air** | 0.00 | -990 | -1002.0 | -997.0 | -996.2 | -994.9 | -992.9 | -992.4 |
| 2 | **Polypropylene** | 0.92 | -100 | -102.0 | -103.4 | -104.0 | -103.8 | -104.0 | -104.6 |
| 3 | **Water** | 1.00 | 0 | 2.6 | 0.0 | 0.1 | -0.1 | -1.7 | -0.7 |
| 4 | **Nylon** | 1.15 | 100 | 100.8 | 100.6 | 98.1 | 99.3 | 98.3 | 98.2 |
| 5 | **Acrylic** | 1.19 | 125 | 135.7 | 135.8 | 135.2 | 153.0 | 134.3 | 134.2 |
| 6 | **Delrin** | 1.42 | 340 | 323.1 | 319.6 | 317.8 | 317.9 | 316.5 | 317.5 |
| | | **$R^2$** | | 0.9969 | 0.9970 | 0.9969 | 0.9969 | 0.9970 | 0.9970 |
| | | **Noise (HU)** | | 30.43 | 19.25 | 15.94 | 13.87 | 13.75 | 12.53 |

* Noise is obtained by calculating the standard deviation of the water.

**Table 3**. Result of CT number of each material and CT number linearity measured using IndoQCT for tube voltage variation

| | Material | Density (gr/cm³) | CT Number (HU) | | | | |
|---|---|---|---|---|---|---|---|
| | | | Reference | 80 kV | 100 kV | 125 kV | 135 kV |
| 1 | Air | 0.00 | -990 | -1055.3 | -1016.8 | -1003.1 | -999.8 |
| 2 | Polypropylene | 0.92 | -100 | -95.3 | -111.2 | -101.8 | -97.6 |
| 3 | Water | 1.00 | 0 | 0.9 | 13.7 | -1.3 | -1.5 |
| 4 | Nylon | 1.15 | 100 | 94.5 | 105.5 | 109.7 | 103.9 |
| 5 | Acrylic | 1.19 | 125 | 139.1 | 133.8 | 133.6 | 133.6 |
| 6 | Delrin | 1.42 | 340 | 364 | 351.3 | 325.6 | 309.5 |
| | | $R^2$ | | 0.9975 | 0.9972 | 0.9972 | 0.9961 |
| | | Noise (HU) | | 147.05 | 86.5 | 57.34 | 46.63 |

* Noise is obtained by calculating the standard deviation of water

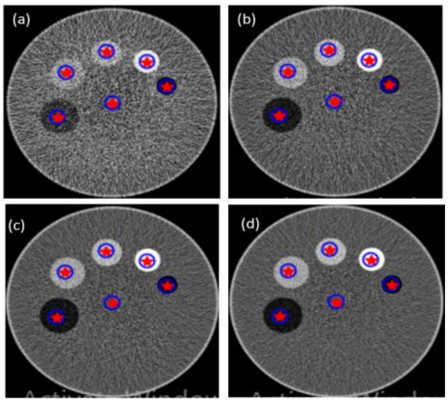


**Figure 4**. Results of automatic placement of ROIs on images of various tube voltages. (a) 80 kV, (b) 100 kV, (c) 125 kV, (d) 135 kV.

Figure 5 shows the results of automatic placement of ROIs of different materials on the variation of slice thickness. Once again, the developed software can detect each target object and place the ROIs within the objects correctly, although the ROIs are not exactly in the center of every object. The results of CT number of each object and the CT number linearity evaluation for slice thickness variation are tabulated in Table 4. Different slice thickness produces various noise levels. Thinner slice leads to more noise levels, that can potentially disturb the segmentation process. However, based on Figure 5, the algorithm is still detect the target object accurately. For slice thickness variation, the overall measured CT numbers are not affected aggressively CT number linearity for slice thickness variation is within the tolerance limit [11].

**Table 4**. Result of CT number of each object and CT number linearity measured using IndoQCT for slice thickness variation.

| | Material | Density (gr/cm³) | CT Number (HU) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Reference | 1 mm | 3 mm | 5 mm | 8 mm | 10 mm |
| 1 | Air | 0.00 | -990 | -995 | -993.8 | -994.4 | -994.3 | -993.7 |
| 2 | Polypropylene | 0.92 | -100 | -105.2 | -104.4 | -103.2 | -103.6 | -103.7 |
| 3 | Water | 1.00 | 0 | -1.5 | -0.5 | 0.4 | 0.7 | -0.8 |
| 4 | Nylon | 1.15 | 100 | 109.2 | 98.4 | 108.5 | 106.4 | 105.3 |
| 5 | Acrylic | 1.19 | 125 | 137 | 134.3 | 137.3 | 136.7 | 137.3 |
| 6 | Delrin | 1.42 | 340 | 317.1 | 317.6 | 317.5 | 317.9 | 318.5 |
| | | $R^2$ | | 0.997 | 0.997 | 0.9968 | 0.997 | 0.997 |
| | | Noise (HU) | | 11.8 | 11.93 | 14.26 | 18.3 | 26.8 |

* Noise is obtained by calculating the standard deviation of water.

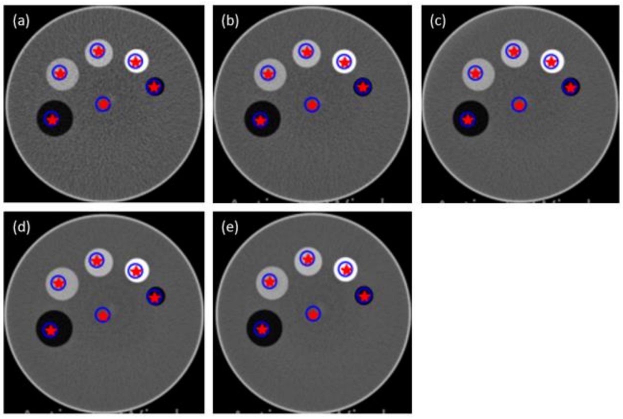


**Figure 5**. Results of automatic placement of ROIs on images of various slice thicknesses (a) 1 mm, (b) 3 mm, (c) 5 mm, (d) 8 mm, and (e) 10 mm

Our developed automated approach has a number of advantages. It can speed up and simplify routine quality control (QC) procedures in healthcare facilities. Its ability to handle a wide range of image condition with various noise levels is one significant advantage. This permits the technique to keep up with precise object detection across various imaging situations. However, our developed algorithm was only tested on one CT scanner. Testing on other CT scanners needs to be performed in the next study. This algorithm for measuring CT number linearity on the TOS phantom expands the previous CT number linearity measurement method which was only limited to AAPM CT Performance phantom [4], ACR CT Accreditation phantom [5], and Catphan phantom [6].

## IV. CONCLUSION

An automatic approach for measuring CT number linearity on the TOS phantom images has been developed and tested with datasets with variations of tube current, tube voltage, and slice thickness. The results showed that the proposed approach can accurately measure CT number linearity across all tube current, voltage, and slice thickness variations. The CT number linearity is still within tolerance limit.

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