IPC
Indonesian Physics Communication
Department of Physics, Universitas Riau, Pekanbaru, Indonesia
p-ISSN 1412-2960 | e-ISSN 2579-521X
Vol. 22 | No. 2
July 2025
Web: https://kfi.ejournal.unri.ac.id
E-mail: kfi@ejournal.unri.ac.id

Evaluation of noise values and homogenity of CT scan image results on head phantom after daily calibration

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ABSTRACT

Evaluation of CT scan image quality is a crucial aspect in ensuring accurate medical diagnosis. This research aims to evaluate noise values and image homogeneity of CT scans on a head phantom after daily calibration. Evaluation of these two parameters is critical because high noise can interfere with image contrast and lead to clinical misinterpretation, while low homogeneity may indicate artifacts or system inconsistencies that potentially reduce diagnostic reliability. Measurements were performed using Region of Interest (ROI) at five points (one in the center and four at the edges at 12, 3, 6, and 9 o'clock positions) across six image slices, for both head and body modes. The CT scan system used was Siemens SOMATOM go.Top, with primary scanning parameters for each mode: 120 kV voltage, 265 mA current (head) and 220 mA (body), as well as Hr40f and Br40f kernels. Research results show that the CT number homogeneity values in head mode ranged from -1.96 to 0.81 HU, and in body mode from -1.78 to 1.28 HU; all were within the tolerance limit of 0 ± 4 HU. Noise values for head mode ranged from 3.49 – 3.67 HU and body mode from 4.98 – 5.37 HU, also within standard tolerance limits. These findings indicate that the CT scan system functions properly and meets diagnostic imaging quality standards. Additionally, these results support the importance of implementing periodic quality control as part of improving radiological service quality and strengthening patient safety standards in medical facilities.

Keywords: CT scan; homogeneity; noise; quality control

Received 29-04-2025 | Revised 15-06-2025 | Accepted 08-07-2025 | Published 31-07-2025

INTRODUCTION

A CT scan (Computed Tomography Scan) is a diagnostic procedure that utilizes X-rays and computer technology to produce detailed images of internal organs, including the head, neck, chest, abdomen, and upper and lower limbs [1]. This technology is highly effective in assessing the condition of blood vessels, including those in the head, heart, and limbs. A CT scan can be used to evaluate the heart's blood vessels without the use of heart-lowering medications. Furthermore, this technique also helps assess blood flow (perfusion) in the brain. The information obtained through a CT scan is crucial for decision-making regarding stroke treatment, accelerating intervention, and reducing the risk of disability.

However, the image quality produced by a CT scan is significantly affected by two main factors: noise and CT value homogeneity. High noise can cause the loss of important image details and reduce tissue contrast, while low homogeneity can indicate an uneven signal distribution, either due to systemic interference, beam imbalance, or detector errors. The challenge is that noise and homogeneity measurements often exhibit variability between machines and over time, especially if consistent quality control (QC) is not performed. Furthermore, there is the potential for calibration errors or limited instrument accuracy, which can impact the reliability of imaging results.

Quality Assurance (QA) is a program designed to maintain optimal diagnostic image quality with minimal risk and discomfort to patients. CT scan QA is performed using a built-in phantom to ensure the system's stability and accuracy in producing high-quality diagnostic images, as well as verifying that the radiation dose remains within safe limits before use on patients. This quality assurance has been explained in publications by the International Atomic Energy Agency (IAEA) and the International Society of Radiographers and Radiological Technologists (ISRRT), which emphasize the importance of regular evaluations to maintain image quality [2, 3]. This QA includes Quality Control (QC) conducted periodically, ranging from daily, weekly, monthly, and even annually, to ensure optimal system performance [4]. CT scan image quality can be assessed by the noise level and the homogeneity of CT values in the image by measuring the standard deviation in the Region of Interest (ROI) [5].

Noise is an important indicator for detecting system problems such as detector interference or poor calibration, which can degrade image quality. Noise describes the reduction in contrast resolution of a CT scan image and is calculated in the Region of Interest (ROI), where its value can be determined from the ROI standard deviation [6]. Homogeneity in a CT scan system ensures that CT values remain consistent throughout the resulting image area, which aims to improve imaging reliability in clinical analysis and diagnosis [7]. Homogeneity calculations are used to identify potential artifacts that can affect the quality of CT scan results. Homogeneity is calculated by determining the absolute value of the difference between the average CT value in the central ROI and the average CT value of the four ROIs at the periphery.

Several previous studies have highlighted the importance of daily calibration in reducing noise and improving CT value homogeneity in CT scan imaging. One study by Lestari and Heru (2022) evaluated the noise and uniformity values of CT scan images by comparing the results before and after daily calibration using a water phantom [6]. The results of this study showed a decrease in standard deviation (noise) of 0.01 HU in the head protocol and 0.81 HU in the abdomen protocol after calibration, as well as an increase in uniformity of 0.258 HU and 1.56 HU, respectively. This study demonstrates that daily calibration can have a positive impact on CT image quality.

However, the approach used in previous studies still has several limitations. For example, measurements were only performed on a single central ROI and did not systematically cover the entire peripheral ROI area. Furthermore, these studies did not detail the influence of specific CT machine technical parameters (such as reconstruction kernel and tube current), and did not include slice variation as an evaluative factor.

Insufficient QC can lead to decreased image quality. If the resulting image is difficult to diagnose due to noise or artifacts, a repeat scan may be necessary, which can result in the patient receiving an excessive radiation dose [8]. This study aims to fill this gap by conducting a comprehensive evaluation of noise and spatial homogeneity of CT values across six image slices, using five ROI measurement points (center and four o'clock directions at 12, 3, 6, and 9 o'clock) in both head and body modes. Furthermore, this study used the Siemens SOMATOM go.Top CT scanner system with detailed parameter specifications, which can provide a stronger context for daily QC practices in hospitals. With a more systematic and representative measurement design, this study provides an additional contribution to understanding the performance of CT scanner systems after daily calibration, which has not been thoroughly explored in previous studies.

RESEARCH METHOD

This research was conducted using an experimental approach, with the scanned object being a head phantom from a CT scanner system that had been calibrated according to manufacturer standards. This phantom was 20 cm in diameter and served as a simulation of human head tissue for image quality evaluation. Noise can be calculated using the following Equation (1) [9, 10]:

$$SD = \sqrt{\frac{\sum(x_i - \mu)^2}{n-1}} \quad (1)$$

SD = Standard deviation
x_i = Number of pixel values in ROI
μ = Average pixel value in ROI
n = Total number of pixels in ROI

SD is the standard deviation, where x_i is the number of pixel values or CT values in each ROI, is the average of all CT values in the ROI, and n is the total number of pixels in the ROI. Noise will be zero if all pixels have uniform values, while excessive variation in pixel values will cause an increase in noise [11]. Measurements were performed repeatedly to ensure consistency of results [12]. Scans were performed using head CT protocols (based on head characteristics) and abdominal CT protocols (based on body/abdomen characteristics). The scan parameters used are presented in Table 1 for head mode and Table 2 for body mode.

Table 1. Typical head mode [13].

Parameters	System A
Voltage	120 kV
Current	265 mA
Scan time	1 s
Rotation time	1 s
Shaped filter	Standard
Body region	Head
Kernel	Hr40f

Table 2. Typical body mode (babdomen) [13].

Parameters	System A
Voltage	120 kV
Current	220 mA
Scan time	0.5 s
Rotation time	0.5 s
Shaped filter	Standard
Body region	Body
Kernel	Br40f

Scanning is performed by first placing a 20 cm diameter phantom on the gantry. This process includes installing the phantom support on the examination table, placing the phantom on the support, and aligning the phantom's center with the vertical and horizontal laser indicators to ensure it is at the gantry's isocenter, as shown in Figure 1. The operator can then proceed by opening the "Settings" menu on the computer screen and selecting the "Daily QA" option. The next step is to click the "Go" button to start the system. After waiting for 19 seconds, the operator is prompted to press the "Press Start" button in the "Route Control" section to continue the QC process. The system will then process the data, and within approximately 10 minutes, the QC results will be automatically displayed on the screen [13].

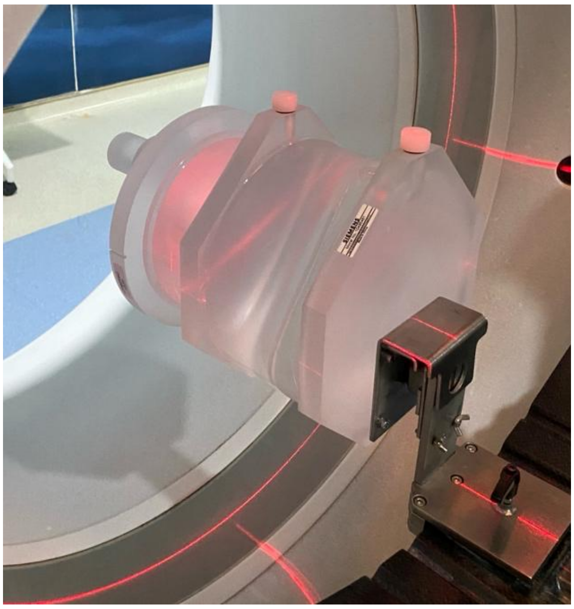

Figure 1. Phantom position at the gantry isocenter [14].

CT values are expressed in Hounsfield Units (HU), a standard feature on CT scanners. HU describes the degree of attenuation of X-rays after passing through an object, reflecting differences in density between organs [15]. HU measurements to assess noise and homogeneity are performed by defining a 10 mm measurement area called a Region of Interest (ROI). The ROI is placed in the center and at the 12, 3, 6, and 9 o'clock positions. ROI placement for both experimental protocols (Head and Abdomen) is performed in the same manner.

Figure 2 shows the determination and measurement of 10 mm ROIs at five points (center, and at the 12, 3, 6, and 9 o'clock positions) to obtain homogeneity values.

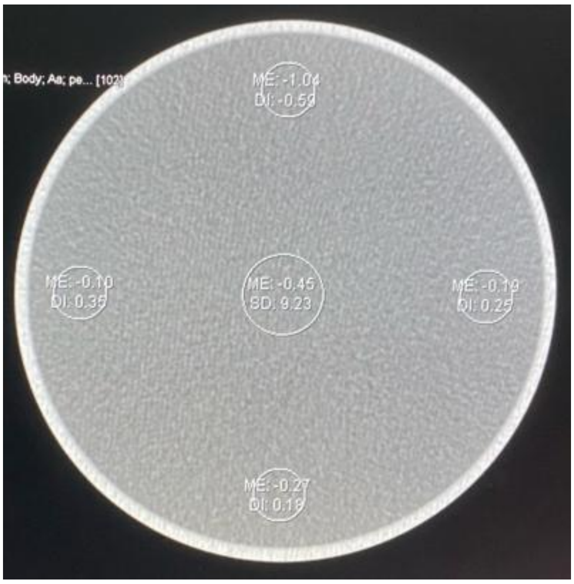

Figure 2. Determining and measuring ROI [14].

Measuring noise and homogeneity in CT scan images presents potential challenges that require attention, particularly those related to external factors such as variations in electrical voltage and room environmental conditions. Unstable electrical voltage can affect the energy output of the X-ray tube, thus impacting the quality of the resulting image. Furthermore, room temperature, humidity, and vibration can also affect instrument performance, including detector sensitivity. Improper phantom placement in the center of the gantry and inconsistencies in calibration procedures can also contribute to increased noise variation in the resulting image.

Ideally, CT values are similar throughout the scan area, and the difference between the central ROI and the peripheral ROI should not exceed 0 ± 4 HU (Hounsfield Units) [2, 13]. The smaller this difference, the better the level of homogeneity achieved. Meanwhile, the permissible limit for noise in CT systems is a standard deviation of 3.90 HU ± 15% for adult heads and 5.02 HU ± 15% for adult heads [13]. Quality control on CT scans is necessary periodically to produce accurate HU values [11].

RESULT AND DISCUSSION

Quality control, which includes evaluating the noise and homogeneity of CT scan images, was performed after daily calibration to identify any deviations that could degrade image quality. The following results were obtained.

Table 3. Head homogeneity results [14].

Slice	Center (HU)	O'clock direction (HU)			
		3	6	9	12
1	-1.96	0.69	0.81	0.71	0.46
2	-1.19	0.42	0.40	0.50	0.21
3	-1.44	0.59	0.32	0.56	0.31
4	-1.67	0.47	0.36	0.27	0.24
5	-1.33	0.36	0.48	0.47	0.33
6	-0.80	0.38	0.35	0.11	0.27

Table Figure 3 shows that the head mode homogeneity values range from -1.96 to 0.81 HU, with the lowest value in the first slice at the center of the ROI (-1.96 HU) and the highest value in the first slice at the 6 o'clock edge of the ROI (0.81 HU). All values obtained remain within the permissible tolerance limit of 0 ± 4 HU for the water phantom, according to applicable standards. This indicates that the measurement results still meet the specified criteria without any significant deviations.

Table 4. Body homogeneity results [14].

Slice	Center (HU)	O'clock direction (HU)			
		3	6	9	12
1	-1.78	1.04	1.16	0.96	0.59
2	-0.82	0.56	0.38	0.52	0.72
3	-1.40	0.78	0.86	1.28	1.04
4	-1.62	0.80	0.62	1.00	0.76
5	-1.16	0.95	0.91	0.83	0.80
6	-0.46	0.54	0.47	0.39	0.31

In Table 4 it can be seen that the homogeneity of the body mode ranges from -1.78 HU to 1 HU, with the lowest values in the first slice at the ROI center (-1.78 HU) and in the fourth slice at the 9 o'clock edge of the ROI (1 HU). All values obtained were within the permissible tolerance limits of 0 ± 4 HU for the water phantom, according to applicable standards. This homogeneity value indicates that the distribution of X-rays received by the detector remains even, resulting in consistent and reliable image quality [16].

Table 5. Head noise results [14].

Slice	Results (HU)	Status
1	3.67	In tolerance
2	3.55	In tolerance
3	3.53	In tolerance
4	3.58	In tolerance
5	3.49	In tolerance
6	3.50	In tolerance

The results in Table 5 show that the image noise value in head mode is in the range of 3.49 to 3.67 HU. This value is still within the specified tolerance limit, which is 2.88 to 4.48 HU (3.90 HU ± 15%).

Table 6. Body mode noise results [14].

Slice	Results (HU)	Status
1	5.37	In tolerance
2	5.18	In tolerance
3	5.04	In tolerance
4	5.14	In tolerance
5	5.02	In tolerance
6	4.98	In tolerance

In Table 6, the image noise values range from 4.98 to 5.37 HU, as shown in Table 4.6. Overall, the results show that all measured values are within the specified tolerance range. The range is between 4.27 and 5.77 HU, which is within the specified tolerance range of 5.02 HU ± 15%.

These findings have important implications for clinical practice, as high noise levels or low homogeneity can cause image artifacts and loss of fine structural detail. This can increase the risk of misinterpretation by radiologists, especially in complex anatomical areas such as the brain or abdomen. Therefore, maintaining noise and homogeneity levels within acceptable limits is crucial for producing accurate images and supporting sound clinical decision-making. This also helps avoid the need for repeat scans, which can increase patient radiation exposure. This study suggests that CT image quality evaluation should not be limited to noise and homogeneity parameters, but should also include other aspects such as spatial resolution and low-contrast detection capability. Furthermore, the use of multiple phantom types and regular, long-term monitoring are recommended to improve the accuracy of quality control and the overall reliability of the CT system.

CONCLUSION

Daily quality control (QC) on CT scans was successfully implemented by evaluating two main parameters: CT value homogeneity and image noise using a 20 cm diameter water phantom. The CT value homogeneity test results for the head mode showed values ranging from -1.96 to 0.81 HU, while for the body mode, they ranged from -1.78 to 1.28 HU. Both modes were within the permissible tolerance limit of 0 ± 4 HU. Meanwhile, the image noise test results for the head mode showed values ranging from 3.49 to 3.67 HU, within the tolerance range of 2.88 to 3.90 HU, and for the body mode, they ranged from 4.98 to 5.37 HU, also within the tolerance range of 4,275.77 HU, as stipulated by Siemens Healthineers and the IAEA. This difference indicates that technical parameters, such as tube current and reconstruction kernel, affect the performance of the resulting images.

This finding underscores the importance of consistently implementing daily quality control (QC) as a preventative measure to maintain the quality of diagnostic imaging. Implementing noise and homogeneity evaluations as key indicators in daily QC can help radiologists detect potential system malfunctions early. This has a direct impact on reducing the risk of misdiagnosis and minimizing the need for repeat scans, thereby improving patient safety and the efficiency of CT scanner use in medical facilities. Overall, the QC results demonstrate that the CT scanner system performs optimally and meets applicable standards, making it suitable for diagnostic imaging services.

ACKNOWLEDGEMENTS

We would like to express our gratitude to all parties who have provided support and contributions to this research. Special appreciation goes to the Supervisor and all lecturers in the Physics Department at Matana University for their guidance and knowledge, as well as to the Hospital for providing the opportunity and facilities to conduct this research.

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