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# Simulation of photomultiplier tube malfunction and its effect on SPECT imaging system

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# Simulation of photomultiplier tube malfunction and its effect on SPECT imaging system

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**Abstract**. Ring artifact appears on the image from SPECT (Single Photon Emission Computed Tomography) imaging system is related to the uniformity. Generally, ring artifacts arose due to the poor performance of the photomultiplier tubes (PMT) in the gamma camera. If one of the PMT cannot perform optimally, defects known as ring artifacts on the image will occur. Detecting the position of the PMT malfunction is a challenge. To study the detection of ring artifacts due to PMT malfunction, artifact reconstruction was conducted by masking one of the PMT on the gamma camera using a copper sheet sizes $4 \times 4$ cm$^2$ and thickness 1 mm. The position of the copper sheet was varied on the horizontal $(x)$ and vertical $(y)$ axes from the center of the detector. Jaszczak phantom without inserts (cold rods and sector cold rods) was used as an imaging object during acquisition. The image results obtained are ring artifact if the copper sheet is positioned on the $(x,0)$, and half-ring artifact on the $(0,y)$.

## 1. Introduction

SPECT commonly use as a diagnostic imaging modality in nuclear medicine. It requires routine quality control (QC) before being used to obtain a high-quality image. QC of the SPECT system consists of three parameters; homogeneity, contrast, and spatial resolution [1]. Artifact, which causes the poor image quality, that appeared on the image from SPECT imaging system must be considered.

Artifact is a defect that appears on digital image processing. Those artifacts arose from several cases; such as from radiopharmaceutical sources [2], gamma camera [3], patient [4], and image acquisition to reconstruction procedures [5]. Some methods conducted to detect and reduce those artifacts. Analytical methods for identifying the circular and noncircular artifacts were introduced by Gullberg [6]. O'Connor and Vermeersch tried to quantify the magnitude of ring artifact and its relation with image noise [7]. The annular ring sampling technique was used for quantifying ring artifact on the image by Madsen [8]. Nonetheless, the best way to minimize those artifacts that appear in the image is by doing a better QC [9].

Ring artifact is related to the homogeneity parameter, in other words, uniformity of the image. Generally, those artifacts arose from gamma cameras on SPECT imaging systems [10]. The gamma camera consists of the collimator, NaITl crystals and PMT arrays in detecting the emitted radiation from the radiopharmaceutical source used [11]. Ring artifact can be generated from angle-shifted collimator from COR (Center of Rotation), which made mispositioning of radiation count in the image

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reconstruction [12]. Even using a multi-pinhole collimator design, the artifact still exists [13]. As well hybrid system like SPECT-CT new design will generate artifacts [14]. The performance of PMT must be considered too, consider temperature increased on one of the PMT in the array can generate serious artifacts [15]. Likewise, one more important thing is maintaining the collimator from radioactive contamination, and the motion of the patient cannot be ignored [16].

In this research, uniformity measurement was conducted based on the QC protocol using a double head SPECT system. The Jaszczak phantom was used as an imaging object by removing the inserts (cold rods and sphere rods) and Tc-99m used as a radiopharmaceutical source. Continuing from the previous research [17], a PMT malfunction simulation was made by masking in face of the parallel hole LEHR (Low Energy High Resolution) collimator which convinced as in front of PMT position using the copper sheet. The position of the copper sheet then varied above, below, left, and right from the center of one of the heads, so that the image results with artifact due to PMT malfunctions will be obtained.

## 2. Methods


**Figure 1.** SPECT dual head imaging.

The SPECT variant Siemens Symbia E series intevo 16 with dual-head gamma cameras is used as the imaging system (Figure 1). The measurement of uniformity used a Jaszczak phantom Flangeless Deluxe type with the insert was removed so that it only a cylindrical phantom with a diameter of 20.4 cm, height 18.6 cm, and a volume of 6.4 L. Tc-99m radiopharmaceutical sources of approximately 3 mCi widely used as radioactive sources for imaging were mixed in water on the phantom until uniformly distributed (resulting the activity concentration to be approximately 16 kBq/mL).

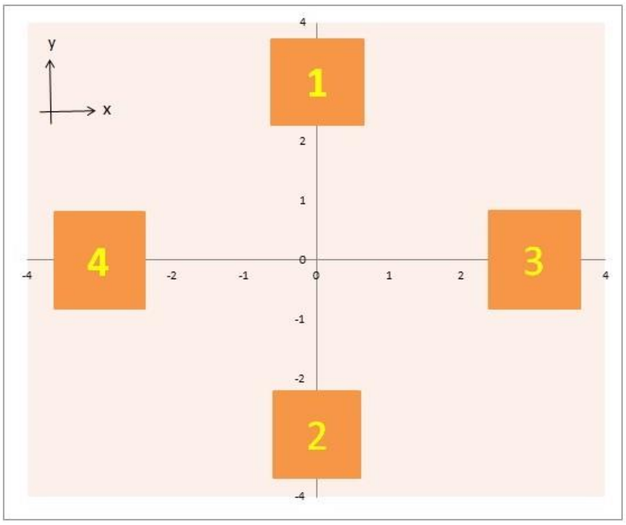
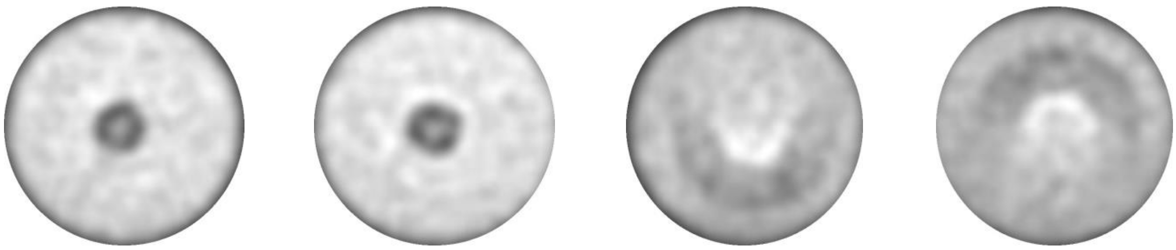



**Figure 2.** Variation position of copper sheet ondetector; [1] (0,3), [2] (0,-3), [3] (3,0), [4] (-3,0).

The positioning of the copper sheet, size 4 × 4 $cm^2$ and thickness 1 mm, as shown in the Figure 2 was used to cover the PMT so that the incoming radiation was attenuated. It was done to reconstruct the ring artifact in the resulting image and to simulate the malfunction of one of the PMT in the array on the gamma camera. The phantom is positioned at the center of the FOV (Field-of-View). The rotation of each gamma camera was 180° clockwise. The detector distance was set as close as the phantom and two gamma cameras can be moved. Image acquisition was conducted for 15 minutes for each copper sheet position. The resulting image slice was 128 slices with size 128 × 128 pixels and slice thickness 0.3 cm. Furthermore, image reconstruction generated by using filtered back projection technique and Shepp-Logan filter, including attenuation correction using Chang's method.

## 3. Result and Discussion

The artifact image was reconstruction was shown in the Figure 3. Artifact that generated from these images divided by three types; upper half-ring artifact, lower half-ring artifact, and possibly ring artifact. The upper half-ring artifact generated from the PMT malfunction at position (-3,0), while for the bottom half-ring artifact from position (3,0). For the full ring artifact, it was the result of PMT malfunction which is at (0,3) and (0,-3). Therefore, it can be concluded that ring artifact will be formed if the PMT malfunction is in position $(0,y)$ with $y \in \mathbb{R}$. The difference between the ring artifact generated at the PMT malfunction positions (0,3) and (0,-3) was the image slice numbers that artifact founded. For position (0,3) ring artifact appeared on slice numbers 45-54, while for position (0,-3) ring artifact appeared on slice numbers 85-94.



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

**Figure 3.** Artifact image reconstruction from PMT malfunction at position (a) (0,3), (b) (0,-3),(c) (3,0) and (d) (-3,0).

The artifact image generated from the attenuation of copper material when the acquisition was performed. Although it can still receive radiation from radiopharmaceutical sources, the PMT can be considered degradation because the presence of artifact (both half-ring and full-ring) is visible. This can be seen from the distribution of pixel values on image.

For the half-ring artifact, it generated because during acquisition each gamma camera only rotate 180° [18]. For the position of the malfunction $(0,y)$, it will generate artifact on the COR during acquisition. Logically the shape of the artifact with PMT malfunction $(0,y)$ generate full circle (without ring) according to the shape of the collimator used. The possibilities as to why those ring artifact occured was emitted radiation scattering occurs in the copper sheet, thus it will produce secondary electron and new emitted photon radiation that allowed into the PMT [19].

The shape of the ring artifact (both half and full) was not smooth on the sides considering the LEHR collimator used will produce artifact at the edge [20]. To identify more accurate, it was necessary to quantify the ring artifact on image. Plot profile from image was taken from image as example shown in Figure 4, and the resulted plot profile in Figure 5. Thus the width of the ring is measured using imageJ. The width of the half ring (both generated above and below) was approximately 4 cm. However, the full ring artifact has a ring width of approximately 1 cm, with an annulus diameter of 2 cm. If the total measured from edge to another end edge of the ring artifact, the full ring artifact is actually approximately the same size as the copper sheet used. In other words, the reconstruction of ring artifact at the $(0,y)$ position with a copper sheet was still incorrect. Nevertheless, for predict the location of PMT malfunction, it can still be considered. By knowing the generated form of the artifact (half-ring or full-ring), it can identify the problem of which part of the PMT has been degradation or severe damaged.

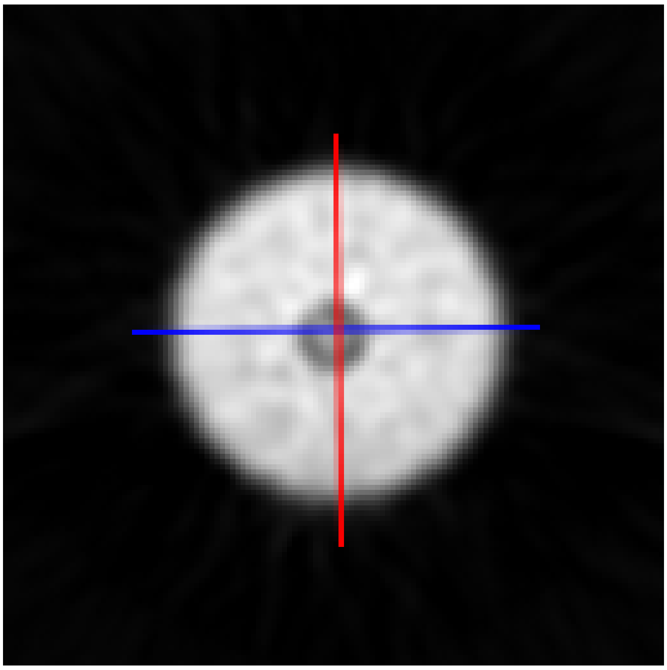


**Figure 4.** Blue line and red line used for plotting the profile of artifact image.

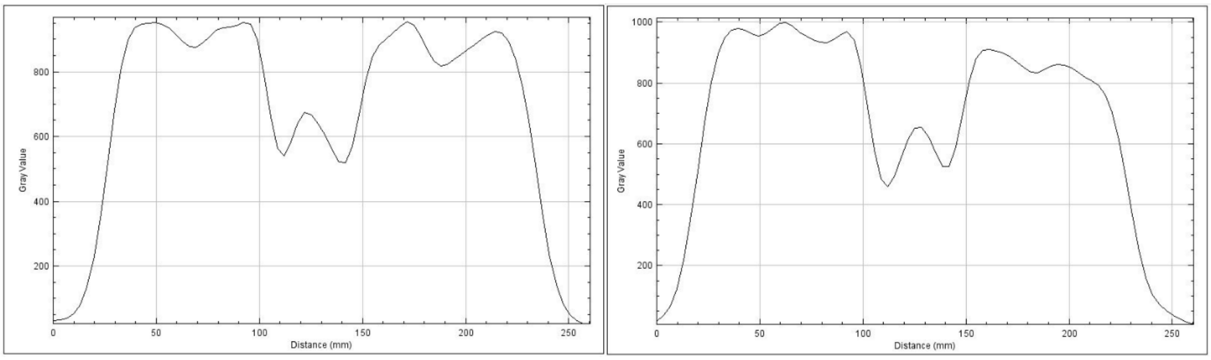



**Figure 5.** Plot profile distance in mm vs gray value generates from blue line (left) and red line (right).

## 4. Conclusion

Detecting ring artifact due to PMT malfunction (masking at possible PMT position by copper sheet) can be conducted by made acquisition of the phantom uniformity section. It can be studied to find out the location of where the degraded PMT is. For using dual head gamma cameras which rotate 180° during acquisition, ring artifact generated in half-ring form if PMT malfunction position at $(x,0)$ and full-ring form at $(0, y)$ with $x, y \in \mathbb{R}$. These results probably can make it easier to repair the damage that occurs to the gamma camera detector due to PMT malfunction. For the further investigation, analysis of the position of the PMT malfunction that produces ring artifact can also be done by comparing the image results obtained by performing a Monte Carlo simulation.

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