Development of industrial single photon emission computed tomography (ISPECT)

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Abstract. Industrial single photon emission tomography system utilized the gamma-ray emission of radioactive tracer to images the cross-section of tracer distribution for industrial process monitoring and diagnosis. In this paper, 36 units of Sodium Iodide, NaI scintillation detectors were used to study flow in a pipelines. The detectors were arranged in two geometrical arrangement, a hexagon and nonagon configuration. The detectors are connected to three 12-channel gamma counter which is controlled by data acquisition and image reconstruction software developed for the system. The images from these two set-ups were also compared with single detector time-average system. Depending on the size of the pipeline used, i.e. for 36 detectors, the nonagon arrangement gives more information on the distribution of the tracer. Thus nonagon set-up is more suitable to be used for representing or demonstrating the image of the tracer distribution in the pipeline.

1. Introduction

Computed tomography (CT) is a computer-aided tomographic process uses irradiation (such as gamma, x-ray, neutron and others) as well as non-irradiation (such as magnetic, electrical capacitance, infrared and others) to produce either two-dimensional or three-dimensional representations of the scanned object both externally and internally. It makes use of computer-processed combinations of many data or images taken from different angles to produce cross-sectional images (virtual "slices") of specific areas of a scanned object, allowing the user to see inside the object without cutting.

In gamma-ray computed tomography system, there are two mode of approach, namely transmission and emission tomography. The different of the two modes are; transmission utilized the attenuation of the gamma ray passing through an object, while in an emission tomography system the interest is on imaging the distribution of the gamma ray itself. Single Photon Emission Computed Tomography, SPECT system is one type of emission tomography where it has been used extensively in medical field but few have reported the uses of this system for industry [1-4]. This is as a result of the applications and problems in industry are diverse from one to another.
Some of previous studies are working on development different types and configuration of industrial SPECT system. One of the earlier groups was Legoupil et.al. who developed a parallel-collimation portable SPECT system consist of 36 NaI(Tl) detectors to investigate the flow pattern in a multiphase flow system [5]. The other more current work in industrial SPECT is Park et.al. who developed a system with 12-gonal diverging collimators [6]. Both SPECT system produced information of the flow patterns in different problem of interest. The results of the system have shown the prospect of an industrial SPECT system for industrial process diagnosis.

In the present work, two configuration of an industrial SPECT system, namely ISPECT is studied for imaging liquid-liquid flow in a pipeline. Both ISPECT systems consist of 36 NaI detectors with hexagonal (6x6) and nonagon (9x4) arrangements.

2. Methodology/ ISPECT system
The ISPECT system developed in this study use 36 NaI scintillation detectors, connected to three 12 port single channel analyzer as shown in Figure 1. The three analyzers were then connected to special (in-house) developed data acquisition software. All of detector in this system has 3 cm lead collimator in front of the detector with 0.5 cm collimator opening. The two configuration of ISPECT studied in this work are hexagon and nonagon. In hexagonal system, there are six arrays of detectors with six detectors in each array. For nonagonal system there are four detectors in an array of overall nine arrays in the system. The maximum diameter of both of these systems is set to be 50 cm and the interest region of scanning is 30 cm in diameter. Figure 2 shows the arrangements of the two systems.

![Figure 1](image)

**Figure 1.** ISPECT hardware system consists of detectors, collimators and gamma counters.

Although the fastest data collection for the system is 50 ms, in this system the counts of gamma-ray were summed up to 1 second for each of 36 detectors. This will allow the system to image the cross section of the tracer flow per seconds. The image for the ISPECT system is reconstructed using Maximum Likelihood-Expectation Maximization method (ML-EM) [7-9] shown in equation 1.

$$y_{j}^{(n+1)} = \frac{y_{j}^{(n)}}{\sum_{i} h_{ij}} \sum_{k} g_{ik} \sum_{l} h_{ij} y_{ik}^{(n)}$$

(1)

The pixel for the images is simulated using Monte-Carlo, MCNPX code [10]. For the time being in the present work, the pixel is set to be 30x30 for 30 cm region of interest, ROI thus each pixel has 1 cm spacing. The average detection efficiency is also calculated from the MCNPX simulation by averaging the total of 648 point source. For the evaluation on position of tracer in reconstructed image, caesium Cs-137 sealed source were used and moved around inside the ROI. In this work, the source is positioned at the centre, 5 cm, 10 cm and 15 cm from the centre of the ROI.
3. Results

3.1. Detection efficiency map
Figure 3 shows the detection efficiency map from the MCNPX simulation for hexagonal and nonagonal ISPECT system used in this study. The average detection efficiency for hexagonal system is $4.24 \times 10^{-5}$ and nonagon system is $4.53 \times 10^{-5}$. Both images show there is high detection on the edge near the detectors. Nevertheless, for nonagon configuration, the image (Figure 3b) shows brighter edge effect as compared to hexagonal image (Figure 3a). The image from nonagon system shows more uniform pixel mapping inside 5 cm from the edge whereby hexagon images has more dark pixel which means low detection in around the center of the ROI. The average detection efficiency for the region without the edge effect, 20 cm inside ROI for hexagon system is $1.488 \times 10^{-3}$ while nonagon system is $1.584 \times 10^{-3}$.

Figure 3. Detection efficiency map of ISPECT system; a) hexagon and b) nonagon.
3.2. Image resolution
The highest image resolution for both systems is mainly depend on the simulated point source mapping which is 1 cm². For evaluating and comparing the image resolution of the two systems, Cs-137 sealed source is placed at the center of the ROI and the image is reconstructed using ML-EM method. Figures 4a (i) and 4b (i) respectively shows the reconstructed images obtained from hexagonal and nonagonal system. Figures 4a (ii) and 4b (ii) are the profile plot across the ROI for the two images. It is evidently indication that both of the systems are able to detect the source at the centre of the ROI. The images show that hexagonal system has more blurring effect near the centre of the images with significant artefact in the surrounding image. For nonagonal system, the surrounding image has no artefact and there is less blurring near the center of the images. The average grey value near the center of the source detected for hexagonal system is 224 while for nonagonal system is 219. Both of these elements are clearly seen in the profile plot across the reconstructed images.

![Reconstructed images of ISPECT for source positioned at the centre with profile plot; a) Hexagon system b) Nonagon system](image)

3.3. Image accuracy/position
Figure 5 shows the reconstructed images from three different positions around the ROI for both of hexagonal and nonagonal system. The source is positioned at 5 cm positive y-axis, 10 cm positive x-axis and 15 cm negative x-y-axis. The images clearly demonstrate that, it can be detected at all position, for both of the system. Although the quality of the reconstructed images is differ from one to another. It can be seen near the edge of the ROI which also means near the gamma detectors, the reconstructed images define the position well in one pixel and there are no surrounding artefacts. At source positioned 10 cm from the centre, blurring effect around the detected position for the hexagonal system are more significant compared to nonagonal system. The reconstructed image for source position at 5 cm of the centre has more blurring but only hexagonal system has surrounding artefacts at positive x-axis direction. The nonagonal system has defined the source position at this point relatively well without much blurring effect.
4. Conclusion
Hexagonal and Nonagonal ISPECT system has been developed and the reconstructed image was compared. The result shows that in detection efficiency mapping, nonagon system has higher edge counts but more uniform pixels value inside 20 cm of the region of interest, ROI. The reconstructed images showed that nonagonal system was better than hexagonal system due to its better resolution and less surrounding artefacts. Both systems have shown good image accuracy where both system could detect different position of the source. On the other hand, the quality of reconstructed images for nonagonal system was better due to the images from hexagonal system that has more blurring effect and has artefacts at 5 cm source position. The study has shown for 36 detectors system, the nonagon arrangement could give more information on the distribution of the tracer and better quality of the reconstructed images and thus, more suitable compare to hexagonal system for imaging the distribution of tracer in the pipeline.

5. References
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