Development of a Simple Gamma Ray Camera Using Handheld Scintillation Detectors

A. Miller, R. Machrafi
University of Ontario Institute of Technology, Oshawa, Ontario, Canada
(alexander.miller@uoit.ca)

A PhD Level Submission

Summary

This paper presents a novel method for making an inexpensive low resolution, wide angle gamma ray camera using a handheld inorganic scintillation detector. The method involves constructing a lead aperture and using motors to create rasterisation points that can be compiled into a pixelated gamma ray image. This method may be used as a module for handheld scintillation detectors so that the detector may be removed for other uses.

1. Introduction

Gamma ray cameras are useful in a wide range of nuclear applications including laboratories, research facilities, nuclear power plant operations, hospitals, nuclear accident scenarios etc. [1]. Unfortunately, gamma ray cameras are exceedingly expensive and most are too large to conveniently carry or mount on small mobile robots for remote radiation sensing. Hence, we present a method for creating a small, inexpensive, low resolution, wide angle gamma ray camera that uses existing handheld scintillation detectors as sensors. Extending on our previous work, we have developed a design concept that will allow handheld scintillation detectors to be mounted inside a lead collimating aperture with motors and a camera. Rasterization points are measured by the scintillation detector and compiled into an 180^o panoramic image and overlaid onto an equivalent visual image.

2. Background

In our previous work [2,3] we developed a MATLAB program that uses an analytical model based on [4] to calculate the counting efficiency of cylindrical inorganic scintillation detectors while measuring point sources of gamma radiation. We incorporated the addition of a lead collimator into the model and developed a method that could be used on a mobile robot to identify the location of gamma ray sources. Our method involves scanning the plane of the robot with the collimated detector, constructing a directional gamma ray profile and recording an 180^o visual panorama with a camera. The gamma ray profile data is overlaid on top of the visual panorama and peaks identify the direction of local gamma ray sources (see Figure 5). Unfortunately, the method is limited to sources near the plane of the robot and cannot convey any information about the elevation of the source. In our current paper we consider extending this method to scan many planes with varying inclination. The result is a data set that represents the horizontal (azimuthal) angle and the vertical (altitude) angle of incoming gamma rays. The data can be compiled and presented in a spherical image. Since the detectors used are inorganic scintillators, the image data can contain information of the gamma ray intensity (source strength) and energy (nuclide identification).

3. Methodology

Our MATLAB model has been used to determine the directional response of our detector while measuring a point ^{137}Cs source. In the model, a cylindrical NaI detector is oriented with the central axis (y-axis) pointing in a given direction and the detection efficiency for measuring the point source is calculated. The detector direction is changed and the efficiency for each direction in an 180^o arc is calculated. The setup of this model is shown in Figure 1.

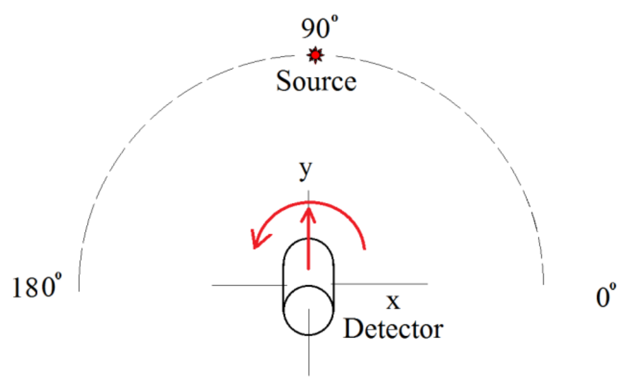

Figure 1 Schematic of point source and detector sweep arc in MATLAB program

The result is plotted in Figure 2 a) which shows the counting efficiency of a 1.5 inch by 1.5 inch NaI detector as a function of the angle of the detector while measuring a point ^{137}Cs source at a distance of 198cm. Notice there is a slight decrease in detection efficiency of the bare detector at 90^o where the geometric efficiency is slightly less. A 1 cm thick lead collimator with a 2 cm lip beyond the end of the detector was also added to the MATLAB model and the detection efficiency for all angles was calculated and is also shown in Figure 2 a). With the collimator present there is a large peak in detection efficiency at 90^o where there is no lead to attenuate the incoming gamma rays. A diagram showing how the lead collimator was constructed is shown in Figure 3.

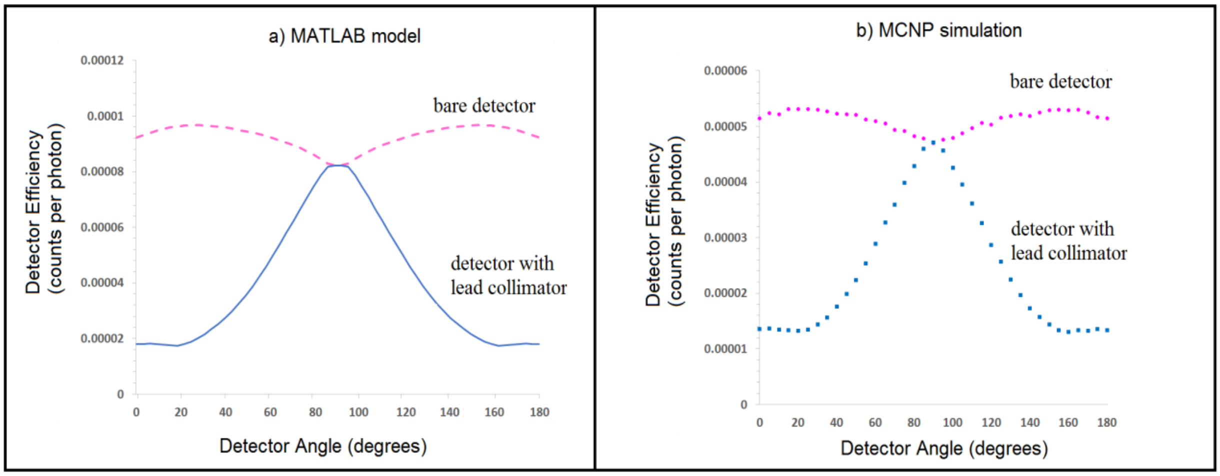

Figure 2 a) Output of MATLAB program for detector measuring point ^{137}Cs source at 198 cm
b) Data from MCNP simulation measuring point ^{137}Cs source at 198 cm

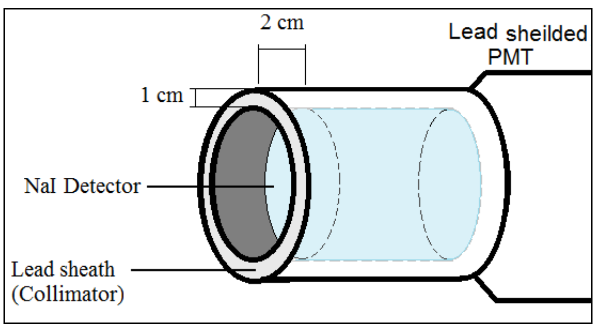

Figure 3 Schematic of NaI detector and lead collimator

The NaI detector and lead collimator were also modeled in the software MCNP. Using Monte Carlo codes is computationally much more expensive than our MATLAB model and takes significantly more time to complete a full directional response model. However, the advantage of using MCNP is that in future work we will be able to significantly alter the geometry of the collimator and add apertures to our system. In addition the MCNP model will track scattered photons and secondary particles as well as photon energy so entire photon spectra can be analyzed instead of merely calculating detector efficiency.

An MCNP simulation for a 1.5 inch by 1.5 inch NaI detector measuring a point ^{137}Cs source at a distance of 198 cm has been constructed. The setup of the simulation is identical to our MATLAB program and the detector efficiency was measured for a bare NaI detector and including a 1 cm thick lead collimator identical to Figure 3. The model was run with a detector angle from 0^o to 180^o in five degree steps. For each directional point an F8 tally (photon energy spectrum) inside the detector was recorded and the detection efficiency (counts per photon) was extracted from the 662 keV bin (^{137}Cs photon energy) from the energy spectra. The result is shown in Figure 2 b). Figure 2 b) agrees very well with the MATLAB simulation presented in Figure 2 a) for both the bare detector and the collimated detector. The efficiency is less in Figure 2 b) because the MATLAB simulation uses the total attenuation coefficient (including photo-electric effect, Compton scattering and pair production) while the MCNP data is only effected by the photoelectric cross section (since only the 662keV bin is used).

Next we extended both the MATLAB model and the MCNP simulation to account for rotation of the detector in the azimuthal direction and altitude direction. Thus the horizontal direction and elevation of a source relative to the detector position can be measured. Both the MATLAB model and the MCNP simulation were used to construct a spherical gamma ray image using sweep scans (equivalent to Figure 1) in multiple altitude planes. The detector efficiency was recorded for each horizontal angle (theta) and altitude angle (phi) while measuring a point ^{137}Cs source located at a distance of 198 cm with a horizontal angle of 90^{o} and 0^{o} altitude.

4 Results

The MCNP simulation was measured with horizontal steps of 5 degrees. Scans were conducted in 5 different altitude planes -4^{o}, 0^{o}, 4^{o}, 8^{o} and 12^{o} to match the panorama image. The result is shown as a partial spherical gamma ray image shown in Figure 4. Notice the location of the gamma source at (90^{o}, 0^{o}) is represented as the center of the red circle.

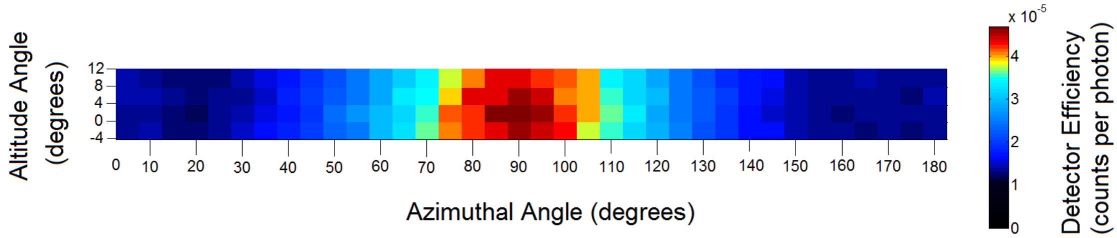

Figure 4 MCNP simulation for ^{137}Cs point source at a distance of 198 cm and position (90^{o}, 0^{o})

In our previous work a single plane was measured with a collimated LaBr detector on a small mobile robot. The output was a graph of detector count rate versus horizontal angle which shows a peak in the direction of a nearby gamma ray sources (identical to the peaks in Figure 2). This graph was overlaid on top of an 180^{o} visual panorama of the local area. Figure 5 shows an example of a scan from our robot with a 1 mCi ^{137}Cs source located in front of the robot.

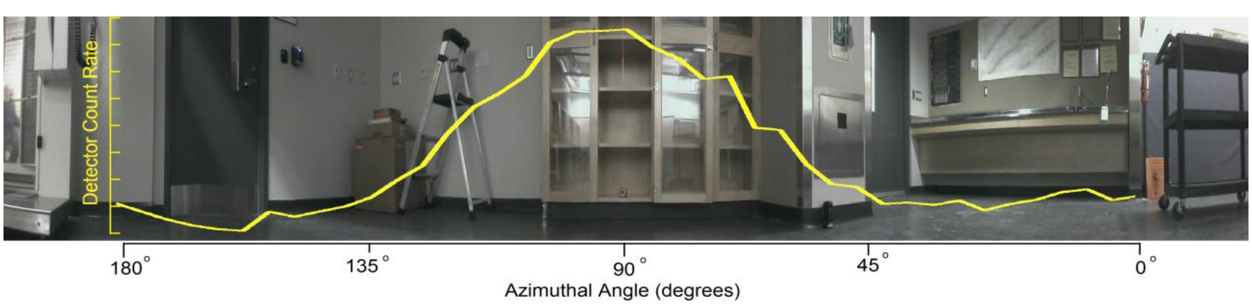

Figure 5 Visual panorama and overlaid gamma ray detector data from mobile robot

The peak in Figure 5 indicates that the source is located in the middle of the field of view. However, the height of the source is not clear. The MCNP simulation data from Figure 4 was overlaid on top of the same visual panorama and is shown in Figure 6. In Figure 6 it becomes apparent that the ^{137}Cs source is located in the middle of the visual panorama and on the bottom shelf of the cabinet. The MATLAB model produced results similar to Figure 6 except with much higher spatial resolution (since many more rasterisation points could easily be recorded in a short time).

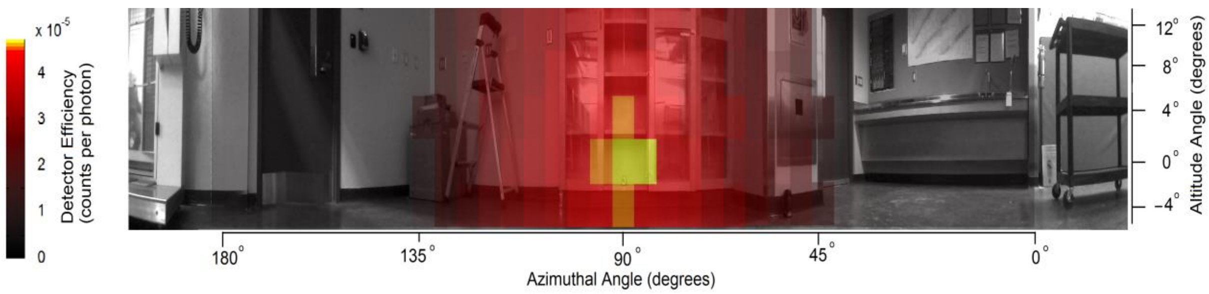

Figure 6 Visual panorama and overlaid MCNP simulation data

5. Conclusion

The directional dependence of cylindrical scintillation detectors with lead collimators has been explored and modeled in MATLAB and MCNP in order to develop a method for creating a simple gamma camera using conventional handheld detectors. Rasterisation points record the gamma ray detection efficiency for each azimuthal angle and horizontal angle. A spherical gamma ray image is constructed using the data and can be overlaid onto a visual panorama in order to show the location of gamma ray sources. Future work involves optimizing collimator and aperture design, incorporating image processing, gamma energy spectra dependence and building an experimental prototype.

6. References

[1] Baek, C.H., An, S.J., Kim, H., Kwak, S.W., Chung, Y.H. (2013). "Development of a Pinhole Gamma Camera for Environmental Monitoring" *Radiation Measurements*, 59, 114–118.

[2] Miller, A. (2014). "Development of a Semi-autonomous Directional and Spectroscopic Radiation Detection Mobile Platform," (MASc. thesis. Dept. Nuclear Eng.). University of Ontario Institute of Technology, Oshawa, Ontario, Canada.

[3] Miller, A., Machrafi, R., Mohany, A. (2015). "Development of a Semi-autonomous Directional and Spectroscopic Radiation Detection Mobile Platform," *Radiation Measurements*, 72, 53–59

[4] Klann R, Lou Q, Fink C. (2006). "Angular Response Functions for Sodium Iodide Detectors," *IEEE Nuclear Science Symposium Conference Record*, volume 6, 1224-1228.