Locating The Radiation Source Using Timepix

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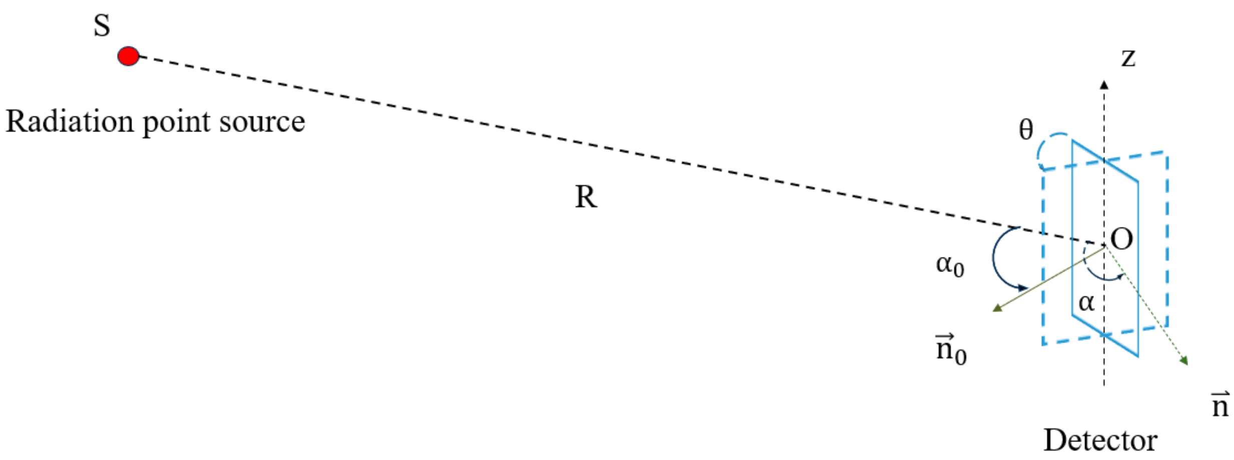

$$n = S \times \varepsilon \times \frac{\Omega}{4\pi} \qquad (1)$$

$$\Omega = \cos\alpha \frac{A}{R^2} \qquad (2)$$

Figure 1. Illustration of the relative positions of the source and detector

- Rotating the detector around the z-axis by an angle of θ will change α.
- The cos(α) will be largest when $\vec{n}$, $\overrightarrow{OS}$, and the z-axis are coplanar (θ = 0°).

➢ **This results in the largest solid angle and count rate.**

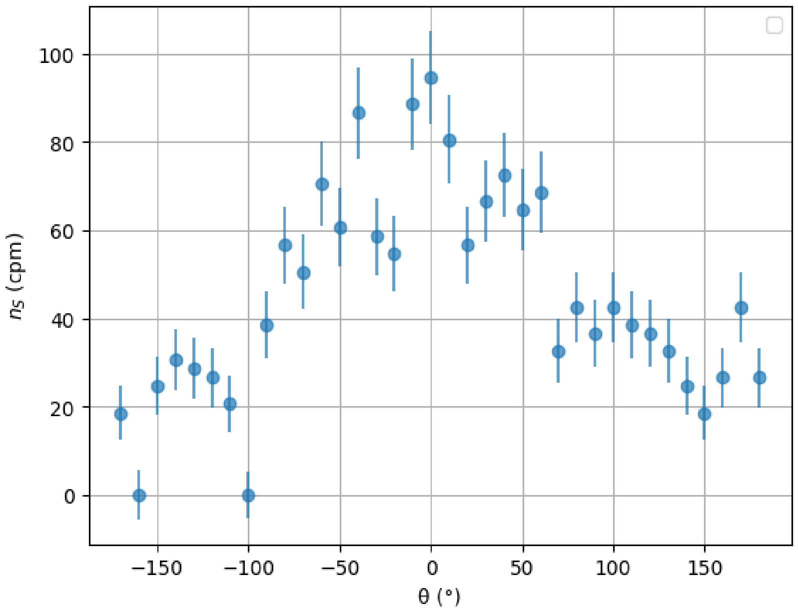

Figure 2. The net count rate of dots (n_S) depending on the detector rotation angle (θ)

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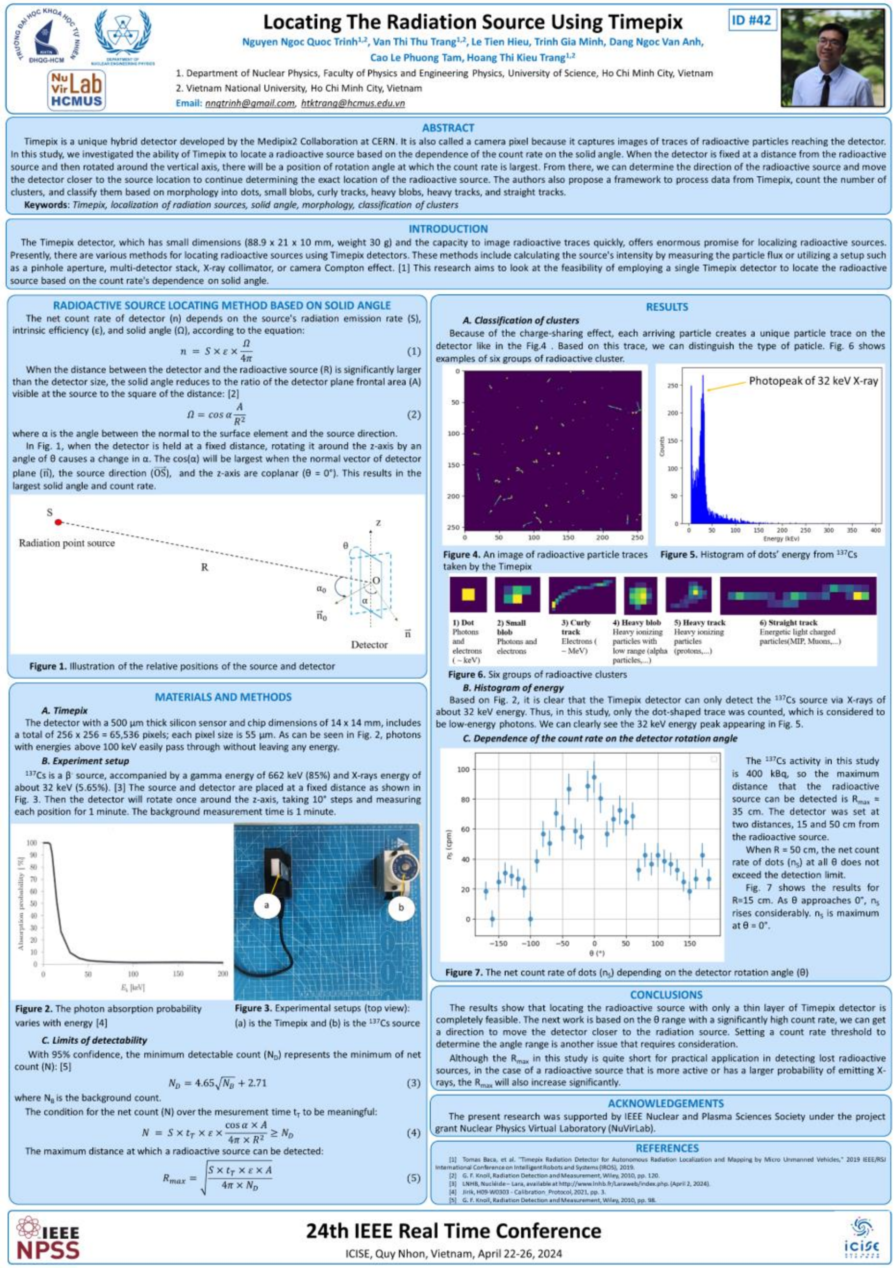
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ABSTRACT

Timepix is a unique hybrid detector developed by the Medipix2 Collaboration at CERN. It is also called a camera pixel because it captures images of traces of radioactive particles reaching the detector. In this study, we investigated the ability of Timepix to locate a radioactive source based on the dependence of the count rate on the solid angle. When the detector is fixed at a distance from the radioactive source and then rotated around the vertical axis, there will be a position of rotation angle at which the count rate is largest. From there, we can determine the direction of the radioactive source and move the detector closer to the source location to continue determining the exact location of the radioactive source. The authors also propose a framework to process data from Timepix, count the number of clusters, and classify them based on morphology into dots, small blobs, curly tracks, heavy blobs, heavy tracks, and straight tracks.

Keywords: Timepix, localization of radiation sources, solid angle, morphology, classification of clusters

INTRODUCTION

The Timepix detector, which has small dimensions (88.9 x 21 x 10 mm, weight 30 g) and the capacity to image radioactive traces quickly, offers enormous promise for localizing radioactive sources. Presently, there are various methods for locating radioactive sources using Timepix detectors. These methods include calculating the source's intensity by measuring the particle flux or utilizing a setup such as a pinhole aperture, multi-detector stack, X-ray collimator, or camera Compton effect. [1] This research aims to look at the feasibility of employing a single Timepix detector to locate the radioactive source based on the count rate's dependence on solid angle.

RADIOACTIVE SOURCE LOCATING METHOD BASED ON SOLID ANGLE

The net count rate of detector (n) depends on the source's radiation emission rate (S), intrinsic efficiency (ε), and solid angle (Ω), according to the equation:

$$n = S \times \varepsilon \times \frac{\Omega}{4\pi} \quad (1)$$

When the distance between the detector and the radioactive source (R) is significantly larger than the detector size, the solid angle reduces to the ratio of the detector plane frontal area (A) visible at the source to the square of the distance: [2]

$$\Omega = \cos\alpha \frac{A}{R^2} \quad (2)$$

where α is the angle between the normal to the surface element and the source direction.

In Fig. 1, when the detector is held at a fixed distance, rotating it around the z-axis by an angle of θ causes a change in α. The cos(α) will be largest when the normal vector of detector plane ($\vec{n}$), the source direction ($\vec{OS}$), and the z-axis are coplanar (θ = 0°). This results in the largest solid angle and count rate.

Figure 1. Illustration of the relative positions of the source and detector

MATERIALS AND METHODS

A. Timepix

The detector with a 500 μm thick silicon sensor and chip dimensions of 14 x 14 mm, includes a total of 256 x 256 = 65,536 pixels; each pixel size is 55 μm. As can be seen in Fig. 2, photons with energies above 100 keV easily pass through without leaving any energy.

B. Experiment setup

^{137}Cs is a β⁻ source, accompanied by a gamma energy of 662 keV (85%) and X-rays energy of about 32 keV (5.65%). [3] The source and detector are placed at a fixed distance as shown in Fig. 3. Then the detector will rotate once around the z-axis, taking 10° steps and measuring each position for 1 minute. The background measurement time is 1 minute.

Figure 2. The photon absorption probability varies with energy [4]

Figure 3. Experimental setups (top view): (a) is the Timepix and (b) is the ^{137}Cs source

C. Limits of detectability

With 95% confidence, the minimum detectable count (N_D) represents the minimum of net count (N): [5]

$$N_D = 4.65\sqrt{N_B} + 2.71 \quad (3)$$

where N_B is the background count.

The condition for the net count (N) over the measurement time t_r to be meaningful:

$$N = S \times t_T \times \varepsilon \times \frac{\cos\alpha \times A}{4\pi \times R^2} \geq N_D \quad (4)$$

The maximum distance at which a radioactive source can be detected:

$$R_{max} = \sqrt{\frac{S \times t_T \times \varepsilon \times A}{4\pi \times N_D}} \quad (5)$$

RESULTS

A. Classification of clusters

Because of the charge-sharing effect, each arriving particle creates a unique particle trace on the detector like in the Fig.4 . Based on this trace, we can distinguish the type of particle. Fig. 6 shows examples of six groups of radioactive cluster.

Figure 4. An image of radioactive particle traces taken by the Timepix

Figure 5. Histogram of dots' energy from ^{137}Cs

1) Dot: Photons and electrons (~ keV); 2) Small blob: Photons and electrons; 3) Curly track: Electrons (~ MeV); 4) Heavy blob: Heavy ionizing particles with low range (alpha particles,...); 5) Heavy track: Heavy ionizing particles (protons,...); 6) Straight track: Energetic light charged particles(MIP, Muons,...)

Figure 6. Six groups of radioactive clusters

B. Histogram of energy

Based on Fig. 2, it is clear that the Timepix detector can only detect the ^{137}Cs source via X-rays of about 32 keV energy. Thus, in this study, only the dot-shaped trace was counted, which is considered to be low-energy photons. We can clearly see the 32 keV energy peak appearing in Fig. 5.

C. Dependence of the count rate on the detector rotation angle

The ^{137}Cs activity in this study is 400 kBq, so the maximum distance that the radioactive source can be detected is R_{max} = 35 cm. The detector was set at two distances, 15 and 50 cm from the radioactive source.

When R = 50 cm, the net count rate of dots (n_s) at all θ does not exceed the detection limit.

Fig. 7 shows the results for R=15 cm. As θ approaches 0°, n_s rises considerably. n_s is maximum at θ = 0°.

Figure 7. The net count rate of dots (n_s) depending on the detector rotation angle (θ)

CONCLUSIONS

The results show that locating the radioactive source with only a thin layer of Timepix detector is completely feasible. The next work is based on the θ range with a significantly high count rate, we can get a direction to move the detector closer to the radiation source. Setting a count rate threshold to determine the angle range is another issue that requires consideration.

Although the R_{max} in this study is quite short for practical application in detecting lost radioactive sources, in the case of a radioactive source that is more active or has a larger probability of emitting X-rays, the R_{max} will also increase significantly.

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REFERENCES

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