

Development and evaluation of a portable gamma-ray imaging device based on Compton imaging algorithm

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1. Introduction

Major ports and airports operate radiation portal monitors to detect radioactive materials in imported cargo. When an alarm is triggered, customs officers must open the cargo container and measure each item individually with a survey meter to identify the source, since the location of the radioactive material inside the container cannot be determined in real time. This process is time-consuming and increases the risk of radiation exposure for customs officers, raising the demand for a portable device capable of visualizing the location of radioactive materials on site.

Gamma-ray imaging devices can address this need; however, most commercially available devices have performance limitations such as low measurement efficiency, narrow usable energy range, and low image resolution, and are not optimized for customs inspection sites. Therefore, in this study, the Radiation Equipment Fab. developed a portable Compton imaging device based on a small room-temperature semiconductor CdZnTe (CZT) detector that visualizes the spatial distribution of gamma-ray-emitting radioactive materials and identifies their nuclides. To confirm the practical usability of the device, the imaging performance of the device was quantitatively evaluated at the Radiation Equipment Fab. using a point radioactive source.

2. Methods and Results

2.1 Development of a portable gamma-ray imaging device

The Radiation Equipment Fab. developed a portable Compton imaging device using a CdZnTe (CZT) sensor manufactured by H3D Co.[2], consisting of four CZT crystals, each measuring 2.2 cm × 2.2 cm × 1.0 cm. Gamma-ray response data, including the interaction position and energy within the CZT crystal, were acquired from all directions (4 π geometry) and recorded in list-mode format together with the crystal number and interaction time. This response data was applied to a Compton imaging algorithm[1] to reconstruct the spatial distribution of gamma-ray sources.

In order to obtain visual images that allow operators to intuitively grasp the location of radioactive materials, we implemented an image registration algorithm that

registers the gamma-ray image obtained through a simple back-projection algorithm with the optical image obtained using an RGB camera. Gamma-ray images were acquired over a hemispherical space with pixels defined at 1-degree intervals in a spherical coordinate system, and the RGB camera provided optical images based on the same coordinate system using a fisheye lens with a 210-degree field of view and a resolution of 1920 × 1080. The center-axis coordinates of the CZT sensor and the optical camera were calibrated based on the spherical coordinate system, and after aligning the reference positions of the two images, the transparency of the optical and gamma-ray images was adjusted to improve visibility. A battery with a lifetime of more than 10 hours was used to power the radiation sensor and RGB camera, and a housing was designed to integrate the radiation sensor, RGB camera, and battery into a single wireless, portable device.



Fig 1. A developed portable gamma-ray imaging device

2.2 Imaging performance evaluation

The image registration algorithm was implemented in the data acquisition and gamma-ray imaging program, and its imaging performance was quantitatively evaluated using angular resolution. A Cs-137 point source was placed in front of the device, and each gamma-ray interaction within the sensor was used to generate a Compton cone through the back-projection algorithm; as increasing numbers of incident gamma rays were accumulated, the overlapping cones revealed the location of the radioactive source, as shown in Fig. 2.

Since Compton imaging is performed in a spherical coordinate system, the influence of the source-to-detector distance is removed, allowing the imaging performance to be assessed through angular resolution. Profile graphs of the Compton image were obtained in the horizontal and vertical directions, the background contribution was removed by linearly interpolating the edges of each peak, and the full width at half maximum (FWHM) of each profile was calculated. As a result, angular resolutions of 26.1° and 17.1° were obtained in the horizontal and vertical directions, respectively. Fig. 3 shows the source localization capability of the device, with the gamma-ray image overlaid onto the optical image acquired by the RGB camera.

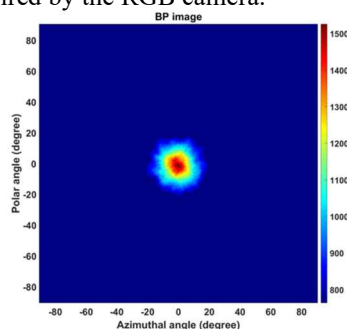


Fig 2. Radiation image of a point source

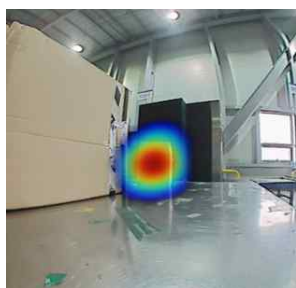


Fig 3. Radiation image overlaid onto optical images

2.3 Nuclide analysis

In addition to imaging, a nuclide analysis function was implemented in the program to identify the type of radioactive material. The data acquisition program converts the gamma-ray energy information received from the detector into a histogram and displays it as an energy spectrum; at this time, not only single-interaction events but also multi-interaction events within the detector are combined by summing the reaction energies and displayed together in the same energy spectrum. The energy spectrum data displayed on the nuclide analysis panel can also be saved by the user in a text file format.

Based on the Becquerel library[3], gamma-ray peaks are automatically recognized within the energy spectrum, and nuclides are identified by comparing the recognized peaks against a pre-defined nuclide-specific gamma-ray energy peak library. To test the nuclide analysis algorithm, an experiment was conducted using a Cs-137 source with an activity of $90 \mu\text{Ci}$ placed in front of the detector, confirming that the presence of the nuclide could be automatically identified.

3. Conclusions

In this study, we developed a portable gamma-ray imaging device based on a room-temperature CdZnTe semiconductor sensor that can detect the location of radioactive materials inside customs clearance goods without opening them, and analyze their nuclides. The imaging performance of the device was quantitatively evaluated using a Cs-137 point source, achieving angular resolutions of 26.1° and 17.1° in the horizontal and vertical directions, respectively, confirming its capability for source localization. This enables precise identification of contamination sources in imported goods, thereby improving the efficiency of radioactive contamination detection and enabling the establishment of effective response strategies against radioactive sources. Ultimately, this protects the health of customs officers, inspectors, and the public. Additionally, by incorporating feedback from actual customs field operations and conducting on-site validation during the equipment development process, we developed a portable gamma-ray imaging device optimized for customs field operations.

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