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

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1. Introduction

With increasing public concern and awareness regarding radioactive materials, the importance of radiation detection for imported cargo is rising. Consequently, the demand for radiation detection devices is expanding across various fields, including applications such as radioactive contamination monitoring and special nuclear material detection.

Gamma-ray imaging devices can be used for the location detection of radioactive materials within customs clearance goods; however, most commercially available devices have performance limitations such as low measurement efficiency, narrow usable energy range, and low image resolution. Additionally, functions such as radioactive material visualization and automatic nuclide analysis are not optimized for customs inspection sites, limiting their practical application. Therefore, in this study, the Radiation Equipment Fab. developed a portable Compton imaging device based on a small room-temperature semiconductor CZT detector sensor that can visualize the distribution of gamma-ray-emitting radioactive materials in cargo and analyze their nuclides. The performances of the device were evaluated at Radiation Equipment Fab. and also demonstrated the device in actual customs sites.

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 small room-temperature semiconductor CZT detector sensors. The portable Compton imaging device contains four CZT detector sensors, each measuring 2.2 cm × 2.2 cm × 1.0 cm. When gamma rays enter the CZT crystal, the gamma ray response location information and response energy information within the CZT crystal is recorded in list-mode format using an ASIC circuit..

In order to obtain visual images that allow operators to intuitively grasp the location of radioactive materials, we implemented an image registration algorithm that can register gamma-ray images obtained through image reconstruction algorithms and optical images obtained using an RGB camera. For gamma ray image acquisition, we used a simple back projection image reconstruction algorithm[1]. When acquiring gamma-ray images, images were acquired over a hemispherical space with pixels defined at 1-degree intervals in the spherical coordinate system.. The RGB camera also provided optical images based on the spherical coordinate system. Therefore, the center axis coordinates of the CZT detector sensor and the optical camera were calibrated based on the spherical coordinate system. After calibrating the reference positions of each image, the two images were aligned, and the transparency of the visible image and gamma-ray image was adjusted to improve visibility. Intel's D435i device was used as the RGB camera[2], and a battery with a lifetime of more than 10 hours was used to power the radiation sensor and RGB camera, enhancing portability. A housing was designed to integrate the radiation sensor, RGB camera, and battery into a single device. Furthermore, the device was designed to operate wirelessly to enhance user convenience.

Fig 1. A developed portable gamma-ray imaging device

2.2 Development of the data acquisition program and the gamma-ray imaging program

This image matching algorithm was implemented in the data acquisition program and the gamma-ray imaging program. After placing a Cs-137 radioactive source with 90 uCi in front of the device, it was possible to acquire images that represent the location of the radioactive material. As shown in Fig. 2, each gamma-ray interaction within the sensor was used with a simple back-projection algorithm to generate a Compton cone. With increasing numbers of incident gamma rays, the cones overlapped, thereby revealing the location of the radioactive source.

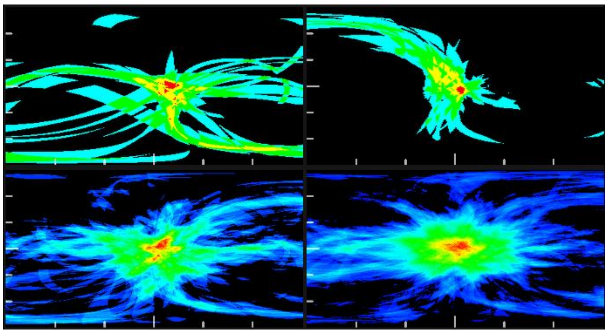

Fig 2. Gamma-ray image acquisition process using the Compton imaging algorithm

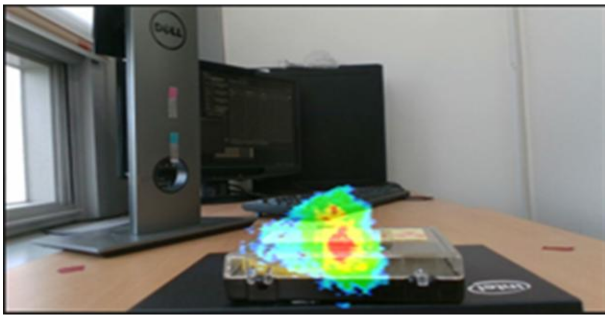

Fig 3. Results of radioactive material visualization before the optimization

In addition, we optimized the image reconstruction algorithm for acquiring gamma-ray images as shown in figure 4. To improve the performance of the existing image reconstruction algorithm, we implemented and utilized a Gaussian filter within the algorithm.

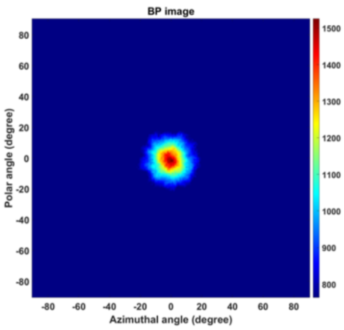

Fig 4. Gamma-ray image with Gaussian filter applied

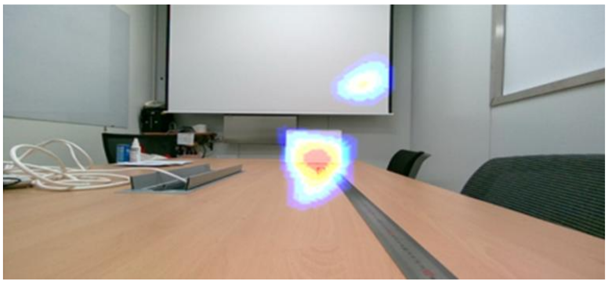

Fig 5. Results of radioactive material visualization after the optimization

In addition, in the program, a nuclide analysis function was implemented to identify the type of radioactive material. The data acquisition program converts the gamma-ray energy information received from the detector sensor into a histogram and displays it as an energy spectrum. At this time, not only events that reacted once in the detector but also events that reacted two or more times are combined with the reaction energy information for each reaction and displayed as an energy spectrum. In addition, the energy spectrum data displayed on the nuclide analysis panel can be saved by the user in a text file format.

Based on the Becquerel library, gamma ray peaks can be automatically recognized within the energy spectrum, and nuclides can be identified based on the pre-reflected nuclide-specific gamma ray energy peak library. To test the nuclide analysis algorithm, an experiment was conducted using a Cs-137 source with 90 uCi on the front of the detector sensor, and it was confirmed that the presence or absence of the nuclide could be automatically identified.

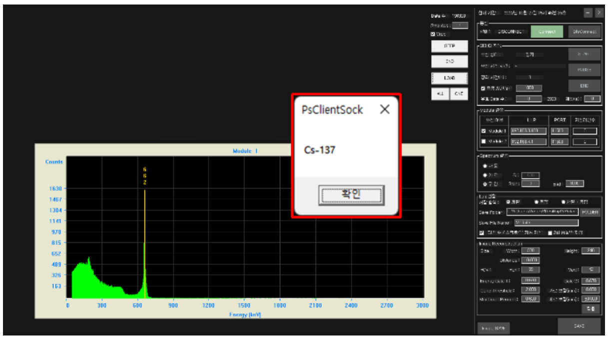

Fig 6. Results of the nuclide analysis of radioactive materials

3. Conclusions

In this study, we developed a portable gamma-ray imaging device based on room-temperature semiconductors that can detect the location of radioactive materials inside customs clearance goods without opening them and to precisely analyze the nuclides of the materials. 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 while enhancing the efficiency of radioactive contamination detection operations. Additionally, by incorporating feedback from actual customs field operations and conducting on-site validation during the equipment development process, we were able to develop a portable gamma-ray imaging device optimized for customs field operations.

REFERENCES

[1] R.W. Todd et al., A proposed γ camera. Nature 251, Vol. 5471, p.132, 1974.

[2] 1. “Intel RealSense D400 Series Product Family Datasheet”, 2019.