# Development of Hemispherical Rotational Modulation Collimator (H-RMC) Imager

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## 1. Introduction

The radiation image-based detection/monitoring technique has become an important research topic in nuclear security field for effective response to radiation emergency and accident. Among various modalities of radiation imaging system, rotational modulation collimator (RMC)-based imaging is considered as a promising imaging method with little complexity in the system configuration. Recently, we have suggested an RMC imaging system combined with the pulse shape discrimination (PSD) capable $Cs_2LiYCl_6$:Ce (CLYC) scintillation detector as a dual-particle imager [1,2].

However, the conventional RMC system is the limited field-of-view (FOV) imposed by cylindrical geometry. As an alternative design for the RMC, we proposed a new hemispherical collimator design which can extend the FOV nearly up to ~2π in solid angle [3,4]. Here, in this study, we introduced overall H-RMC system configuration, and the Monte Carlo simulations performed to investigate the feasibility of developing H-RMC RMC system. In addition, measurement experiments were conducted for testing the imager performance.

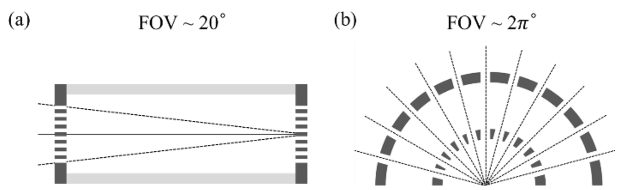


Fig. 1. Field of view (FOV) of RMC: (a) conventional design and (b) H-RMC.

## 2. Methods and Results

### *2.1 Hemispherical RMC (H-RMC) system*

The design of the RMC system is shown in the Fig. 2. The RMC system mainly consists of inner/outer collimator masks, radiation detection system and rotation control system. Based on our pervious study, the diameter of collimator masks was decided to be 20 cm for outer mask and 6 cm for inner mask [3]. The slit/slat interval was set to 7°, and the collimator masks were set to 0.5 cm-thick stainless steel because of its high strength and ease of production.

The detector for the H-RMC system is a CZT-based co-planar grid (CPG) detector manufactured by Kromek (Kromek Group plc, United Kingdom), and the CZT crystal is 1×1×1 $cm^3$. It offer ~4.4% energy resolution at 356 keV. For the rotation control of collimators, we utilized HF-KP053 servo motor system (Mitsubishi, Japan). A timing pulley and belt were mounted onto the driver tube and servo motor which was used to transmit the power from a servo motor to rotate the H-RMC.

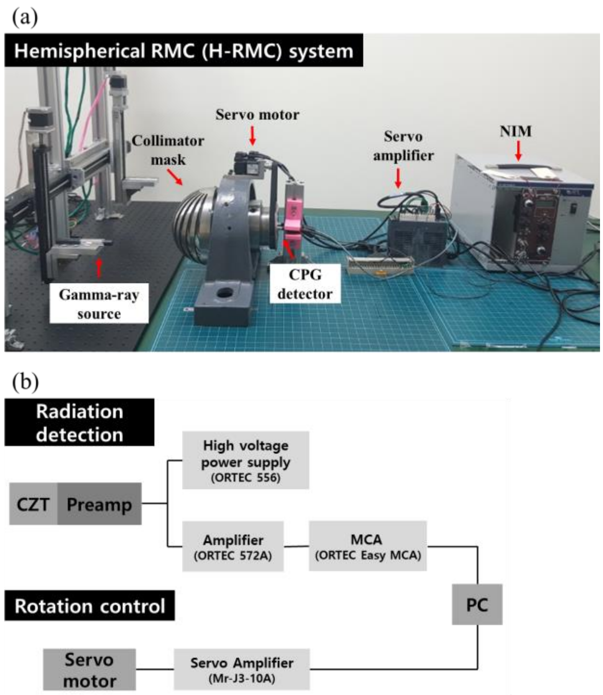


Fig. 2. (a) H-RMC system and (b) block diagram of radiation detection/rotation control system.

### *2.2 Fundamental characteristic of modulation patterns*

We validated our proposed H-RMC system by verifying a fundamental characteristic of modulation patterns using MCNP6. In the simulations, we assumed the point sources of 356 keV gamma rays, and detector for H-RMC system was modeled to be our CPG detector.

Fig. 3 shows the effect of a phase shift of modulation patterns according to the degree of rotation between source points. For different source positions located at the same distance from the rotation axis, the degree of the source's rotation relative to the rotational axis exactly matched the degree of the pattern's shift. The detailed comparison results are shown in Table 1. This fundamental characteristic of modulation patterns can be exploited to indicate the source position.

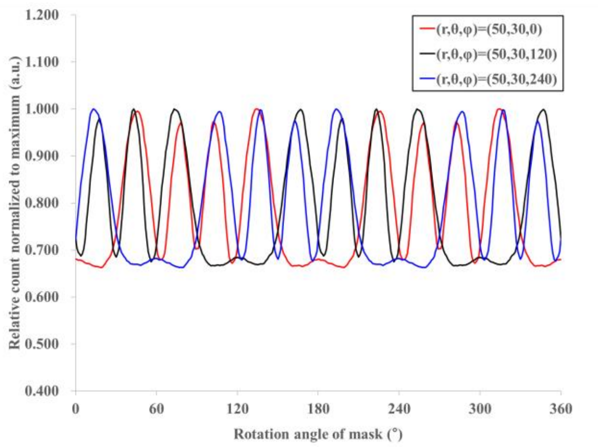


Fig. 3. Modulation patterns of various source positions obtained by MCNP6.

Table 1. Comparison between phase shift in modulation patterns and rotation degree of the sources.

| $(r, \theta, \varphi)$ | Rotation degree of source | Degree of modulation pattern shift |
|---|---|---|
| (50 cm, 30°, 0°) | 0° | 0° |
| (50 cm, 30°, 120°) | 120° | 120° |
| (50 cm, 30°, 240°) | 240° | 240° |

*2.3 Measurement experiment: Image reconstruction*

A 10.64 μCi Ba-133 source (R-type, Eckert & Ziegler, Germany) was positioned on the mounting unit, of which the location can be precisely controlled by the Arduino Mega 2560 board. Modulation patterns obtained by the measurement experiments and the MCNP6 simulations are shown in Fig. 4. Measured modulation patterns were well matched with MCNP6 simulation results.

For the reconstruction of radiation images, the maximum-likelihood expectation maximization (MLEM) algorithm was employed as described in [2]. Fig. 5 shows the reconstructed image of the 356 keV gamma rays emitted from (r,θ,φ)=(25 cm, 30°, 180°). The circles in Fig. 5 represent the actual source position we actually placed, and the imaging algorithm estimated the true source position as the point which has highest value of MLE. Therefore, reconstructed images gave promising results on utilizing H-RMC system for radioactive material monitoring and detection. However, the MLEM also estimated symmetric point (r,θ,φ)=(25 cm, 30°, 0°) as true source location. This is an intrinsic artifact caused by the symmetric mask design. We are currently carrying out an investigation of the asymmetric slit/slat configuration to solve the intrinsic artifact. Results of the asymmetric mask study will be reported in our following study.

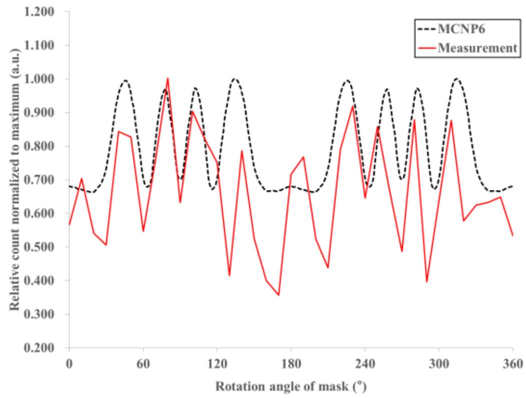


Fig. 4. Comparison of modulation patterns obtained by measurement and MCNP6 at $(r,\theta,\varphi)$=(25 cm, 30°, 180°).

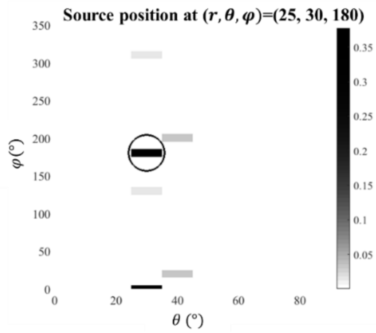


Fig. 5. Reconstructed image of measured modulation pattern at $(r,\theta,\varphi)$=(25 cm, 30°, 180°).

## 3. Conclusions

In present study, we demonstrated feasibility of the H-RMC imager by verifying the characteristic of the RMC modulation patterns. We confirmed that the measured modulation pattern showed the same morphology with the simulated result. In addition, it was shown that gamma rays can be visualized to estimate the source location of radioactive materials utilizing a H-RMC. It is expected to utilize an effective tool for imaging spatial distribution of radiation sources.

## REFERENCES

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