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DESIGN AND IMPLEMENTATION OF GAMMA RADIATION SOURCE DIRECTION WITH PANORAMIC SENSOR CODING COLLIMATOR (PSCC) SYSTEM

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Abstract

This research work concerns with Panoramic Sensor with Coding Collimator to investigate the direction of the gamma radiation sources by using spectroscopic method. In this research work Gamma Radiation Source Investigation with Panoramic Sensor Coding Collimator (PSCC) system is constructed and the apply program for this system in MATLAB software package is created. NaI(Tl) 3x3 inches scintillation detector has been used for measurement of different gamma radiation sources with some kBq activities: Americium-241, Cesium-137 and Cobalt-60 sources in different distances and directions. By using this system, the unknown direction and the distance of radiation source have been identified. According to the result from measurements, PSCC system can be applied for multi-dimensional measurements and used as device for radiation monitoring and safety.

Keywords: *Direction Identification, Gamma Radiation Sources, Panoramic Sensor Coding Collimator, Radiation Monitoring, Radiation Safety, Scintillation Detector NaI (Tl).*

Introduction

In recent years, radiation and nuclear technologies have been deployed rapidly and broadly in various industrial, economic sectors, society. However, the management, transportation, storage and usage of radioactive sources are complicated by many challenges. Radioactive materials are especially dangerous substances. Any negligent, inaccurate or ignorant manipulation with them can lead to radioactive pollution [1, 3]. In radiation monitoring of the limited or remote areas, it is necessary to determine correctly spatial distribution of a field of radiation and location of the sources [5].

One of the major technical problems is instrumentation of the control over migrations of radioactive materials. Detectors of nuclear radiation with various configurations are applied to solve these problems [1, 5]. Identification of ionizing radiation source is physically limited in the areas (buildings, warehouses, etc.), as well as in mines and wells, therefore highly efficient detection system is necessary to investigate the direction of the source. For these purposes, the most appropriate instrument based on the principle of multiplexed detection of radiation is considered [6, 9]. The panoramic sensor concerns to radiation detection system with coding collimator, which allows the identification of gamma radiation source direction.

AIM

The aim of current research work is to implement the design for investigation of the gamma radiation source's direction by using panoramic sensor with coding collimator system and created application program.

Materials and Method

A. Design Layout of Panoramic Sensor with Coding Collimator (PSCC)

Design layout of Panoramic Sensor with Coding Collimator (PSCC) is intended to solve the coding with collimator, rotation collimation system and the blocking of the radiation measurement [5].

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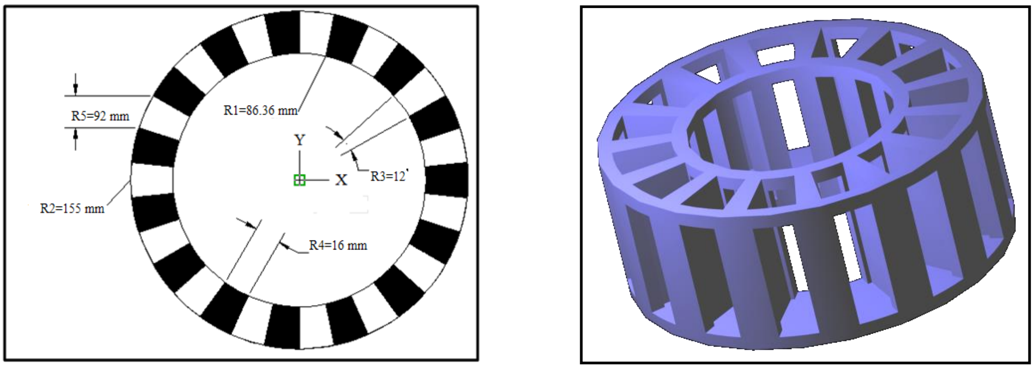
Three-dimensional model describes the collimator created by Auto Desk 3D modelling software. Figure 1(a) and (b) show the 3D view of PSCC design and dimensions of this collimator.



(a) (b)

Figure 1(a) Top View with Dimensions of PSCC and **(b)** 3D View of PSCC

B. Main Characteristics of PSCC

Panoramic sensor with coding collimator is a complete measuring system based on cylindrical geometry with open and close blocks. The dimensions and parameters of the PSCC is shown in table 1 [1]:

Table 1 Typical parameters of PSCC

Overall dimension of PSCC	**Dimension**
Diameter (Outer)	330 mm
Diameter (Inner)	155 mm
Size of collimator	
Height	145 mm
External diameter	155 mm
Internal diameter	86.4 mm
Height of a slot-hole aperture	92 mm
Width of a slot-hole aperture	16 mm
Weight of PSCC	21 kg

C. Determination Methods for Direction of Gamma Radiation Source

Method for investigation of the direction of gamma radiation source (GRSI) is an integrated part of the created design layout of PSCC. The proposed method with more reliability and the shortest time interval will determine the direction and position of the source.

The device is designed to improve the detection of radiation and determine the direction of the source, by using the principle of the multiplex measurements. The measuring data count rate is recorded in several sectors. The result data received from the detector can be represented as follow; [2, 4]

$$y_i = c_i + \beta_0 x_i^0 + \beta_1 x_i^1 + \ldots + \beta_N x_i^N \tag{1}$$

where,

y_i = the count rate of the number of pulses recorded by the detector in the ith direction

$x_i^0, x_i^1, \ldots, x_i^N$ = the count rate of the number of pulses in discrete sectors of decomposing in the ith direction

$c_i =$ the background count rate

$\beta_0, \beta_1, ..., \beta_N =$ coefficient of an integral code transformation for experimental design

The expectation of equation (1) can be expressed in matrix form:

$$\hat{y} = \hat{B} \times \hat{x} + \bar{c} \quad (2)$$

Matrix can be conveniently represented as a product of two matrices, one of which is matrix of experimental resulted data, and the second is matrix of the collimator system. Therefore, the measurement result is as follow;

$$\hat{y} = \hat{A}\hat{T} \times \hat{x} + \bar{c} \quad (3)$$

where,

$\hat{A}$ = representation of matrix

$\hat{T}$ = unit diagonal matrix taking account of the collimator system

Assessment of the desired parameters and their variances can produce using the least square method in either case, if the number of dimension equal to the number of unknown parameters (the square matrix) may use the formula;

$$\hat{x} = \hat{A}^{-1}\hat{y} \quad (4)$$

$$\hat{D}(\tilde{x}) = \left[\hat{A}^{T}\hat{D}^{-1}(y)\hat{A}\right]^{-1} \quad (5)$$

The implementation of these methods was used Circulant-Matrix, built on the basis of sequences which are a set of “0” and “1” located pseudo random order. Rotational shifting the sequence in a particular direction by current position forms rows of the matrix. Thus, Circulant-matrix can be represented as follow;

$$\hat{A} = \left\| \begin{matrix} a_0 & a_{n-1} & a_{n-2} & \cdots & a_1 \\ a_1 & a_0 & a_{n-1} & \cdots & a_2 \\ a_2 & a_1 & a_0 & \cdots & a_3 \\ \bullet & \bullet & \bullet & \cdots & \bullet \\ \bullet & \bullet & \bullet & \cdots & \bullet \\ \bullet & \bullet & \bullet & \cdots & \bullet \\ a_{n-1} & a_{n-2} & a_{n-3} & \cdots & a_0 \end{matrix} \right\|$$

where,

$a_0, a_1, \ldots, a_n$ = elements of the pseudo-random sequence takes the value “0” or “1” [2, 4]

D. Data Processing using Circulant-Matrix Method

To identify the direction for maximum level of radiation, it is necessary to measure the radiation intensity in a given point of the location area along the radial directions (See Fig. 2). The figure 2 shows the geometry of the measurements to identify the direction of improving radiation emission. Firstly, we need to collect the data about the distribution of the flux of gamma radiation in the current location of the detector, and then these data are processed and finally result data from processing is obtained in a convenient form for analysis [4].

The measurements are performed in the radial direction and the count rates are N_1, N_2, N_3 and so on. A dashed line shows the conditional partition of full azimuth angle on the sector and the maximum rotation angle $\Delta\phi$ is equal to the all sectors [6, 7, 8].

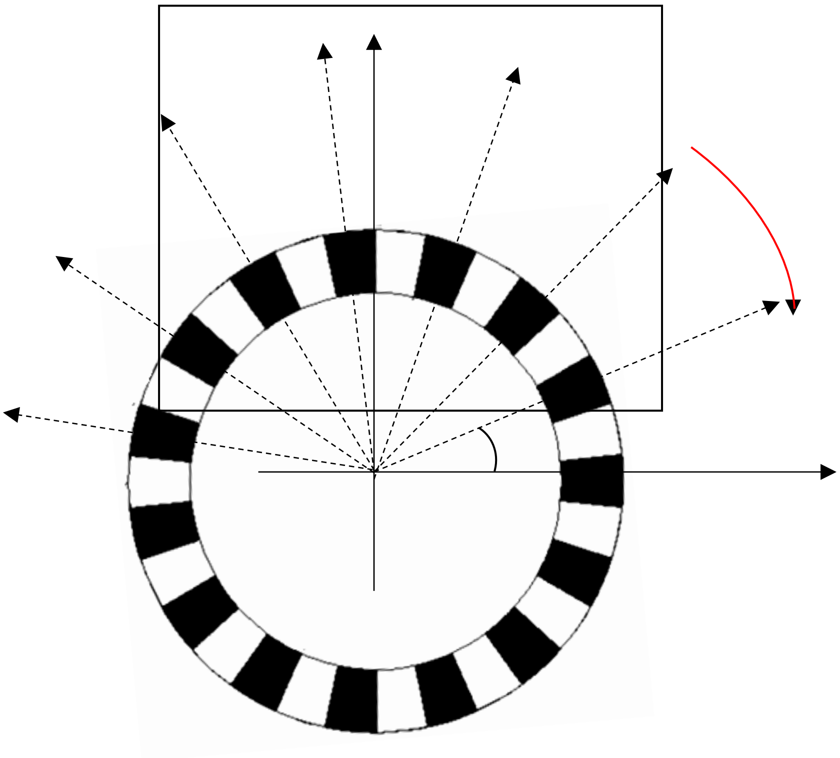


Figure 2 The geometry of the experiment with PSCC System

E. Program of Gamma Radiation Source Investigation with Panoramic Sensor Coding Collimator (PSCC) System

In this research, program for identification of the directions of gamma radiation source was created based on the detection of gamma radiation by CASSY-modules and MATLAB software package. [9]

By using this program, the unknown directions of gamma radiation sources can be determined. After carried out the experiments with program calculated not only the unknown directions, but also distance of radiation source and collimator. The lab-scaled experimental design of the PSCC system is represented in figure 3.

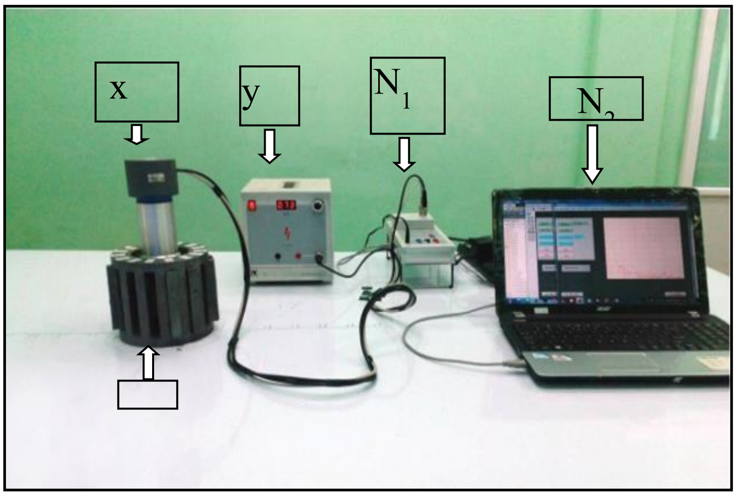


Figure 3 Lab-scaled experimental design of the PSCC system

Program "PSCC" is created in MATLAB-GUI with CASSY-modules. This program controls the measurement of gamma radiation and analyzes the measured data [9]. The program "PSCC" consists of two sub-programs;

(a) Measurement program and

(b) Identification program.

This program can perform the various conditions, such as single- and multi-sources measurements in different directions and distances of gamma radiation sources with different energies and activities. The interface for identification sub-program of PSCC was shown in figure 4.

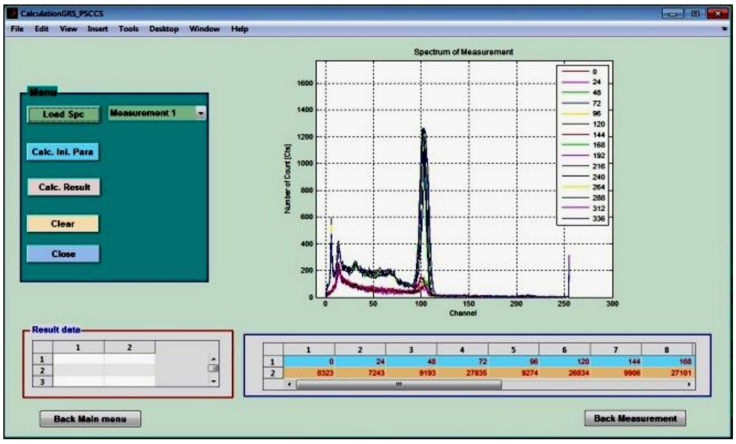


Figure 4 Interface for identification sub-program of "PSCC"

EXPERIMENT

The measurement of gamma radiation was performed by the following procedure:

(1) The detector is placed a position and guided the first slotted-hole aperture to the north.

(2) Then, the set of spectrum data is recorded during the measuring time with 60 sec.

(3) After the measurement, collimator is turned about 24˚ clockwise on its own axis.

(4) Measurement is repeated 15 times by rotating collimator clockwise-direction for the whole collimation system.

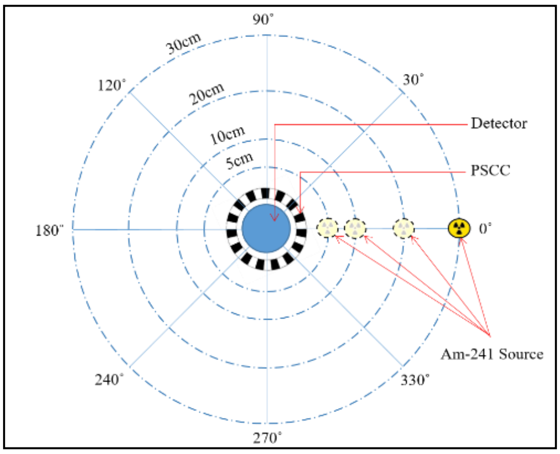


Figure 5 Scheme of Single-Source Measurement with PSCC System

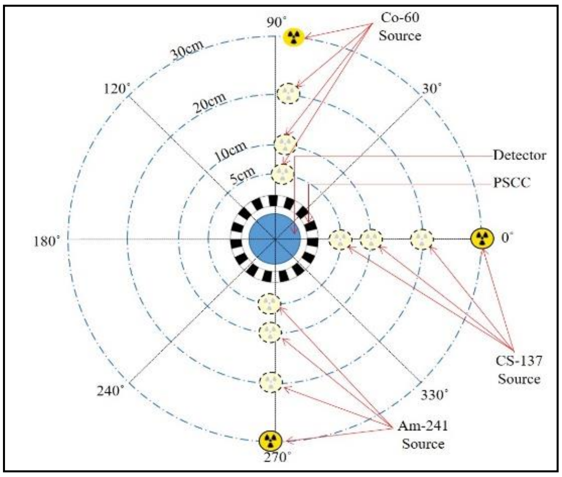


Figure 6 Scheme of Multi-Sources Measurement with PSCC System

By performing above procedure of measurement, Spectra display after 15 times and subsequent matrix can be analysed by the methods. The certain energy range can occur in the result data from the measured spectra. Energy range and the source type from measured spectra can be known in advance by energy calibration with standard gamma radiation sources. The specific energy range can also significantly improve by taking the ratio of the background counts, which in turn improves a certain direction of the source [3].

In this research work, the two types of measurements: single- and multi-gamma radiation sources with various directions and locations have been performed (See Figure 5 and 6).

Result and Discussion

A. Result of Single-Gamma Radiation Source Measurement

For measurement with single-gamma radiation source, ^{241}Am with current activity 370 kBq was chosen. In this measurement, the gamma radiation source was placed in various distances about 5cm, 10cm, 20cm and 30 cm respectively.

The measured result data of gamma radiation source ^{241}Am with various distances from 5 to 30 cm with 60 sec measuring time for horizontal geometric system are expressed in table 2.

Table 2 Results of identification with ^{241}Am in distance from 5 to 30 cm

Meas. No.	No. of Colli-mator	Rot. Angle	5cm		10cm		20 cm		30cm	
			Intensity	Weight Function ($\times 10^3$)	Intensity	Weight Function ($\times 10^3$)	Intensity	Weight Function ($\times 10^3$)	Intensity	Weight Function ($\times 10^3$)
1	1	0	15131	105.5	9940	68.7	7127	49.1	6388	41.5
2	0	24	5741	58.1	5780	47.6	5794	42.1	5605	39.8
3	0	48	5762	76.5	5777	56.2	5689	44.9	5796	42.3
4	1	72	15226	58.6	9683	47.8	7149	42.2	6342	40.3
5	0	96	5618	86.9	5763	60.7	5667	46.6	5541	42.9
6	0	120	5819	58.7	5867	47.8	5674	42.5	5879	40.5
7	0	144	5709	67.8	5852	52.7	5786	43.8	5694	41.6
8	**1**	**168**	**15770**	**68.9**	**10425**	**52.8**	**7179**	**43.9**	**6976**	**44.0**
9	0	192	5458	67.7	5403	52.5	5732	43.9	5605	41.6
10	1	216	14630	68.1	9722	52.4	6859	43.8	6130	41.2
11	0	240	5305	57.6	5463	47.8	5388	42.1	5350	40.4
12	1	264	14273	86.4	9375	60.2	6815	46.0	6345	42.7
13	0	288	5524	57.0	5590	47.3	5508	42.0	5264	40.0
14	1	316	15154	76.9	9825	56.5	7010	44.8	6320	41.9
15	1	336	15379	58.2	9733	47.6	6976	42.0	6267	40.2

From these experimental data, we have found that the dependence of the intensity of ^{241}Am source on measuring distance. Maximum average intensities in open collimator are 15770 counts in 5cm, 10425 counts in 10 cm, 7179 counts in 20 cm and 6976 counts in 30 cm. In close collimator the maximum average intensities 5819 counts in 5cm, 5867 counts in 10 cm, 5794 counts in 20 cm and 5879 counts in 30 cm.

According to the analysis of experimental data with PSCC system, the amount of gamma radiation intensity is decreased about 30-34%. When increasing the distance between the source and detector, the data show that the intensity of ^{241}Am source is remained 66% shown in figure 7(a, b, c, d).

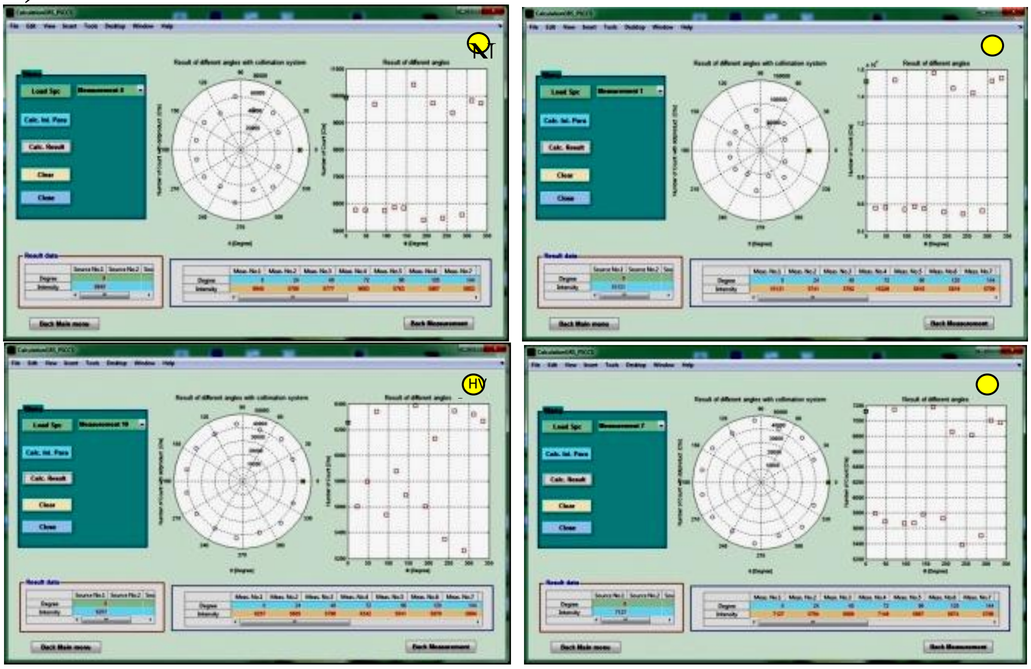


Figure 7(a, b, c, d) Results of identification of ^{241}Am source in distance from 5 to 30 cm and 0 degree location

According to the result of experimental data from table 2, we can determine the direction of ^{241}Am source by the weight function value. Therefore, the directions of ^{241}Am gamma radiation source are located in '0' degree at various distance 5 cm, 10 cm, 20 cm and 30 cm respectively. Maximum weight function values are 105.5x10^3 counts in 5cm, 68.7x 10^3 counts in 10 cm, 49.1x10^3 counts in 20 cm and 44.0x10^3 counts in 30 cm (See Figure 8).

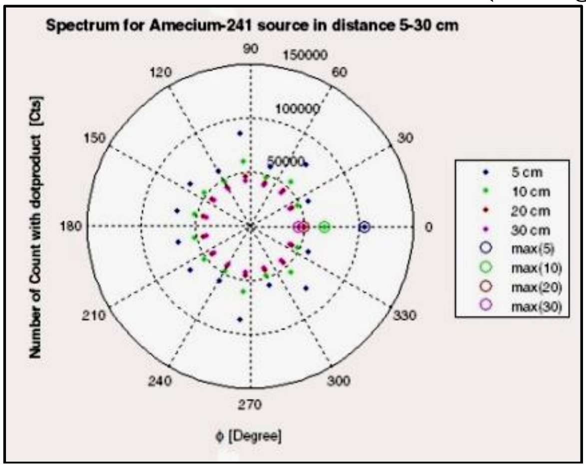


Figure 8 Result of identification to determine the direction of ^{241}Am source by using Circulant-Matrix method

B. Results from Measurement of Multi-Gamma Radiation Sources

In measuring with multi-gamma radiation source, a set of ^{241}Am, ^{60}Co, ^{137}Cs gamma radiation sources with some activity 370 kBq was chosen. In this measurement, the gamma radiation sources are placed in various distances with 5cm, 10cm, 20cm and 30 cm respectively. The measured data of research gamma radiation source ^{137}Cs and ^{60}Co with various distances from 5-30 cm and direction with ^{137}Cs at 0˚(or) 360˚ and ^{60}Co at 270˚ are expressed in table 3.

Table 3 Results of identification with ^{137}Cs and ^{60}Co in distance from 5 to 30 cm

Meas. No.	No. of Colli-mator	Rot. Angle	5cm		10cm		20 cm		30cm	
			Inten-sity	Weight Function ($\times10^3$)	Inten-sity	Weight Function ($\times10^3$)	Inten-sity	Weight Function ($\times10^3$)	Inten-sity	Weight Function ($\times10^3$)
1	1	0	64437	413.9	35692	231.4	17947	117.6	12234	81.7
2	0	24	30059	273.5	21529	175.9	13474	100.9	9976	74.2
3	0	48	50933	336.5	29247	195.2	16194	105.1	11407	75.1
4	1	72	67908	285.2	38268	182.0	19282	104.4	13067	75.6
5	0	96	45148	417.3	27565	233.1	14939	118.8	11066	82.5
6	0	120	24253	272.5	16599	174.3	10769	100.4	8504	73.9
7	0	144	26463	315.9	19718	187.5	12361	102.4	9289	74.0
8	1	168	63129	292.0	34508	182.1	16569	102.1	11558	74.1
9	0	192	23988	336.2	17944	198.1	11516	106.0	9096	75.9
10	1	216	41059	280.0	24294	174.8	12865	97.9	9662	72.0
11	0	240	28707	279.9	20756	173.9	12646	97.9	9702	72.1
12	1	264	62146	338.7	33444	198.6	16568	105.7	11344	75.8
13	0	288	29616	280.5	21681	176.8	13444	99.4	10009	72.9
14	1	316	63665	313.9	34402	186.4	17380	101.0	11920	73.1
15	1	336	51565	274.9	30811	174.5	17002	100.5	12014	73.6

From these experimental data, the variation intensities of ^{137}Cs and ^{60}Co sources were found. Maximum average intensities in open collimator are 67908 counts in 5cm, 38268 counts in 10 cm, 19282 counts in 20 cm and 13067 counts in 30 cm. In close collimator the maximum averaged intensities 50933 counts in 5cm, 29247 counts in 10 cm, 16194 counts in 20 cm and 11407 counts in 30 cm. According to the analysis experimental data with the amount of gamma radiation intensity is decreased about 45%. Increasing the distance between the source and detector shows that the intensity of ^{137}Cs and ^{60}Co source is remained about 55% which are shown in figure 9 (a, b, c, d).

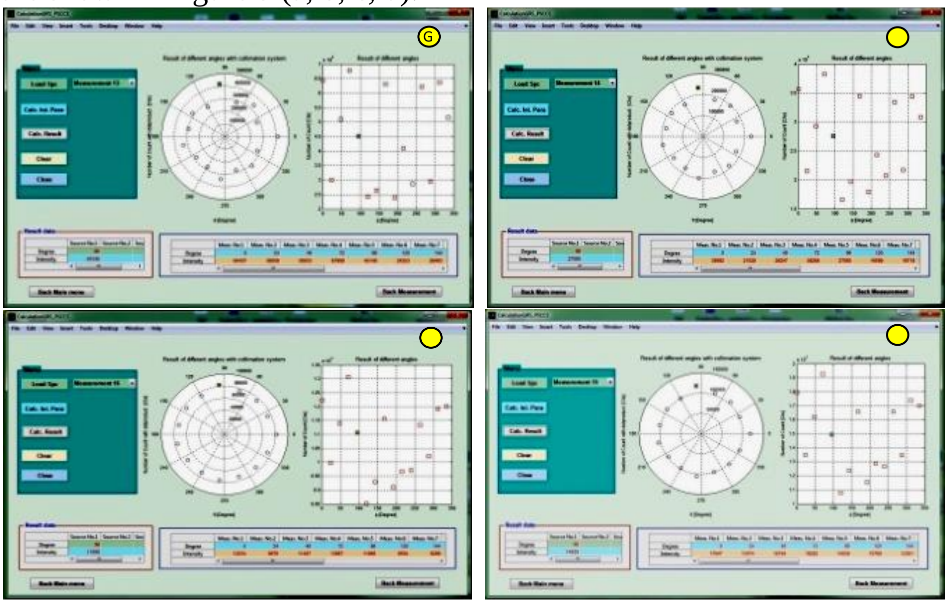


Figure 9(a, b, c, d) Results of identification of ^{137}Cs and ^{60}Co sources in distance from 5cm, 10 cm, 20 cm, 30 cm

The measured data of research gamma radiation source ^{137}Cs and ^{60}Co with various distances from 5-30 cm with 60 sec measuring time are shown in table 3.

According to the result of experimental data from table 3, the direction of ^{137}Cs and ^{241}Co source can be determined by the weight function value. The directions of ^{137}Cs and ^{241}Co gamma radiation source are located in ‘0’ degree at various distance 5 cm, 10 cm, 20 cm and 30 cm respectively. Maximum weight function values are 413.9x10^3 and 417.3x10^3 counts in 5cm, 231.4x10^3 and 233.1x10^3counts in 10 cm, 117.6x10^3 and 118.8 x 10^3 counts in 20 cm and 81.7x10^3 and 82.5x10^3counts in 30 cm (see Figure 10).

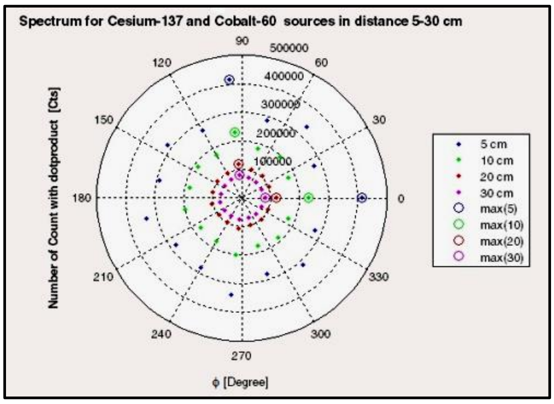


Figure 10 Result of identification to determine the direction of ^{137}Cs and ^{60}Co sources obtained by using Circulant-Matrix method

In table 4, the measured data of research gamma radiation source ^{137}Cs ^{60}Co and ^{241}Am with various distances from 5-30 cm for horizontal direction with ^{137}Cs at 0˚(or) 360˚, ^{60}Co at 90˚ and ^{241}Am at 270˚ are presented.

Table 4 Result of identification with ^{137}Cs, ^{60}Co and ^{241}Am in distance from 5 to 30 cm

Meas. No.	No. of Colli-mator	Rot. Angle	5cm		10cm		20 cm		30cm	
			Inten-sity	Weight Function ($\times10^3$)	Inten-sity	Weight Function ($\times10^3$)	Inten-sity	Weight Function ($\times10^3$)	Inten-sity	Weight Function ($\times10^3$)
1	1	0	64891	447.2	35057	247.5	17705	123.0	12154	84.5
2	0	24	30268	284.1	21350	180.4	13417	102.8	10126	76.3
3	0	48	50922	359.9	29259	204.7	16194	107.9	11753	77.4
4	1	72	73434	303.1	41601	191.6	20511	107.8	13345	78.4
5	0	96	43876	437.5	26514	241.6	14976	122.2	10938	84.3
6	0	120	30351	289.9	20051	183.4	11795	103.7	9979	76.1
7	0	144	27661	335.5	19861	192.2	12632	104.5	9998	75.5
8	1	168	67918	320.2	37441	198.3	18191	108.1	12144	77.5
9	0	192	24224	345.1	17957	203.6	11641	108.9	9981	78.0
10	1	216	46979	303.4	27264	187.1	14164	103.3	10155	74.7
11	0	240	33077	297.6	23620	178.6	13733	100.3	10562	74.1
12	1	264	65614	374.8	37525	221.9	17583	113.7	12133	80.2
13	0	288	30273	289.6	21517	182.1	13582	101.8	10447	75.1
14	1	316	70879	342.2	34223	199.3	17044	105.7	11902	76.0
15	1	336	57499	294.5	34449	180.8	17822	102.6	12730	76.2

From these experimental data, the variation intensity of ^{137}Cs, ^{60}Co and ^{241}Am sources from 5-30 cm are found. According to the analysis of result data with collimation system, the amount of gamma radiation intensity is decreased about 46%. Increasing the distance between the source and detector shows the intensity of ^{137}Cs source is remained 54% which is shown in figure 11(a, b, c, d).

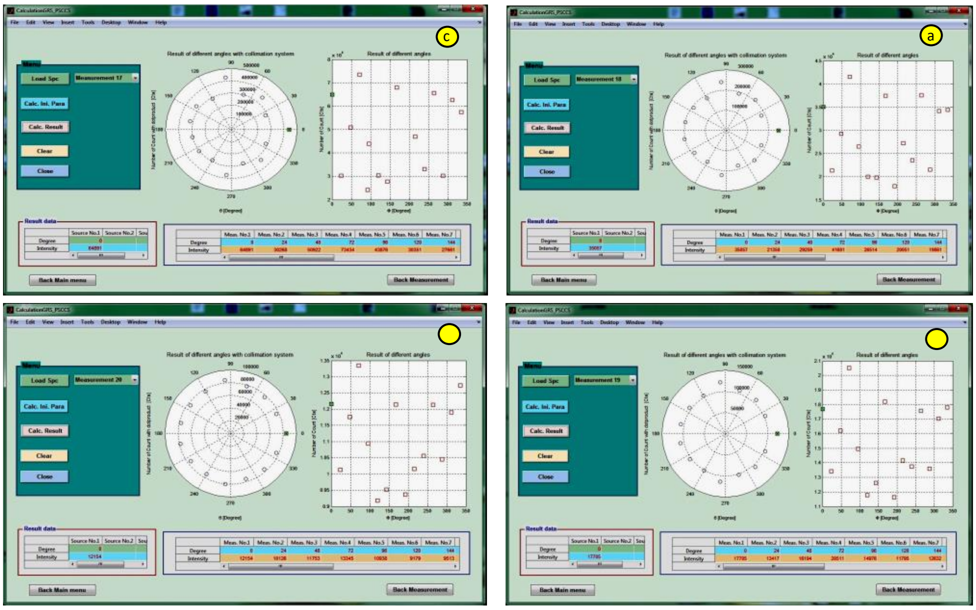


Figure 11(a, b, c, d) Results of identification of ^{137}Cs and ^{60}Co sources in distance from 5cm to 30 cm

According to the result of experimental data from table 4, we can be determined the direction of ^{137}Cs, ^{241}Co and ^{241}Am sources by the weight function value. Therefore, the directions of ^{137}Cs, ^{241}Co and ^{241}Am gamma radiation sources are located in '0' degree at various distance 5 cm, 10 cm, 20 cm and 30 cm respectively. Maximum weight function values are 447.2x10^3, 437.5x10^3 and 374.8.5x10^3 counts in 5cm, 247.5x10^3, 241.6x10^3 and 221.9x10^3 counts in 10 cm, 123.0x10^3, 122.2x10^3 and 113.7x10^3 counts in 20 cm and 84.5x10^3, 84.3x10^3 and 80.2x10^3 counts in 30 cm (see Figure 12).

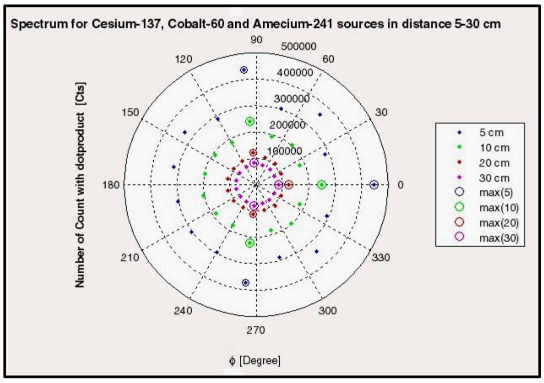


Figure 12 Result of identification to determine the direction of ^{137}Cs, ^{60}Co and ^{241}Am sources obtained by using Circulant-Matrix method

C. Discussion on Overall Results

The design and model for identification the direction of gamma radiation source by Panoramic Sensor with Coding Collimator (PSCC) was constructed. The various measurements with single and multi-gamma radiation sources in different directions and distances are performed.

According to the analysis of result data with different gamma radiation sources in various distances, the amount of gamma radiation intensity is mainly dependent on the energy of gamma radiation source and distance from detector. In addition, the count rate depends on the activity of gamma radiation sources in the same distance of location area, which is detectable range and dependent on detector sensitivity.

The current system can be used in the horizontal measurement with 360˚ field of view and the vertical measurement with 180˚ field of view. In addition, the created PSCC program was operated in the detection system of current design and the directions of researched gamma radiation sources with the result data are obtained. The data of current experimental setup design are good in agreement with theoretical data.

Conclusion

In this research work, the design and model of PSCC system based on single detector system for multi-dimensional measurements is presented. Moreover, MATLAB program is applied to the operation of various measurements with current detection assembly and data acquisition system.

The investigation of the direction of gamma radiation source was used classical mathematical method of Circulant-Matrix, which based on design idea of panoramic sensor with coding collimator system. In addition, program of PSCC is operated in the detection system of current design to identify the directions of researched gamma radiation sources. The proposed design of PSCC can perform the horizontal measurement (transverse arrangement) with 360˚ field of view and the vertical measurement (longitudinal arrangement) with 180˚ field of view.

The results show that the current propose design can clearly identify the unknown direction of single- and multi-radiation sources. Moreover, the activity and radioisotope of single- and multi-radiation sources can also be identified for my further study. Therefore, the propose PSCC system can help to solve the problems related with radiation monitoring, safety and protection.

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