A monitor unit Calculator Program Using Digital Simulator Images

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Abstract

Calculation of the monitor unit is the first important step in radiation therapy. If the calculation of the monitor unit has deviations, it will adversely affect the treatment. The irradiation area, the main factor affecting the calculation of the monitor unit, and if there is any deviation from that area, the monitor unit calculation will have an error too. The objective of this study was to develop a program to calculate the monitor unit from the digital simulator images. Test cases of the radiation area were selected from the IAEA TECDOC 1540 guidelines, and the length of the equivalent radiation areas were calculated in two ways: "Eqs and SQRT", using the JAVA language to determine the radiation field parameters, and "TMR and $S_{c,p}$", calculated from beam data to and calculated the monitor unit by using the approximation method, which was programmed with the Visual Fox Pro language. The results were verified against the IAEA TECDOC 1540 guidelines.

The results, the test case area that calculating on central axis (square and rectangular), the mean difference percent in radiation dose of the equivalent radiation areas with Eqs length passes $\pm 2\%$ tolerance. The mean difference percent in radiation dose of the equivalence areas with SQRT length were not pass $\pm 2\%$ tolerance. The results of the covered test area and off axis, the lengths of Eqs and SQRT radiation areas were not pass $\pm 3\%$ tolerance.

To conclude, the monitor unit calculator program could be used the digital simulator images for calculation the length equivalent radiation area (Eqs). In addition, this program could calculate monitor unit in the central axis accurately.

Keywords: monitor unit calculator program, approximation method, irradiation area image

Introduction

Cancer is the number one cause of death in Thailand (The National Cancer Institute, 2013) and radiation therapy has been playing an increasingly significant role in the treatment of cancer. Effective treatment with radistion therapy requires an accurate and precise treatment planning process (Chan, Karam, Streeter, & Ryoo, 1993). The linear accelerator has been shown as an effective treatment. However, techniques for treating cancerous tumors with the maximum amount of radiation must minimiz radiation exposure to the surrounding organs (Linthout, Verellen, Van Acker, & Storme, 2004). Research conducted by Shafiq, Barton, Noble, Lemer and Donaldson (2009) focused on the number of accidents that occurred with the radiation therapy internationally, in the 30-year period between 1976 and 2007. That study found a total of 7,741 cases, which included 3,125 cases where the patient was treated with radiation levels less than, or greater than, that prescribed by a physician. Thirty-cases had resulted in death.

Hunt, Pastrana, Amols, Killen, and Alektiar (2012) identified the number of accidents annually from each radiation therapy treatment, from 2001 to 2010, which showed that 40% of the accidents radiation therapy were related to the calculation of the field size, depth, inverse square parameters of the monitor unit (MU), and other factors related to the planning process. The level of radiation received by patients is proportionate to the

monitor unit of linear accelerator. Thus, the calculation of monitor unit must be done individually for each radiation therapy patients. The irradiation area approximation is the key factor in the calculation of MU. If the irradiation area approximation has some deviation, the monitor unit calculation will have an error too. The irradiation area can be specified by the irradiation area image from the simulator (Khan, 2010) in which the Digital simulator has been typically used at present . The information of patients and irradiation area image will be stored in a format of DICOM file. In general, the clinical irradiation area approximation from the traditional image simulator will use approximation method as Equivalent square (Sterling, Perry, & Katz, 1964). Regarding the irradiation area in rectangular and square shape, the area of irradiation area in rectangular shape will be equivalent the one in square shape if the two irradiation area have the equal area and perimeter. However, the data storage of radiation field parameter of the linear accelerator is usually stored in a form of table that dosimetric parameters are related to the side length of square from the area of 3x3 square centimeter to 40x40 square centimeter. Hence, if we approximate the irradiation area as a square, take a square root and then use the square root value to approximate the dosimetric parameter and compare the result with Sterling method, it will likely give a similar result but the square root method would be more convenient.

Gesheva (2008) has created 6 MV and 18 MV photon energy monitor unit calculator program, that used fundamental data from approximation compared with data of ESTRO and conducted a radiation approximation based on Standards of Absorbed Dose to Water (TRS-398) to calculate TPR, Sc , Sp and MU for the open irradiation area and the irradiation area with wedge, operated on Microsoft Excel. The experimental result is that the average difference of S_c between the value from approximation and calculation equal to 0.16% and 0.17% for 6 MV and 18 MV energy respectively. The maximum difference of S_p from approximation and calculation equal to 0.4% for both energy. The difference of Sp and the maximum Sp of ESTRO is only 0.5% for both energy, and the TPR of more than 5 centimeter dept is greatly correlated with TPR of ESTRO with the average difference of only 0.5% and the difference of radiation level from approximation and calculation is between ±2 %.

Research Objective

1. To develop the monitor unit calculator program for photon beam by calculating the irradiation area from the digital simulated port field.

2. To Verified results of the monitor unit with IAEA TECDOC 1540 guideline.

Research Methodology and Tools

1. Elekta Precise® Linear Accelerator

2. Simulix EVOLUTION® Digital Simulator

3. 40x40x40 cubic centimeters Water Container

4. PTW Farmer ionization chamber type 30013

5. PTW Unidos E Electrometer

6. Dell Laptop

7. Microsoft Visual FoxPro Computer Language

8. JAVA programing language

9. IAEA TECDOC 1540 Report

Research Methodology

1. Imported Radiation filed parameters（As shown in Figure 1 and Figure 2）

Imported a 6 MV Elekta Precise® Linear Accelerator Radiation filed parameters which consists of a. $S_{c,p}$ Table that shows variety of irradiation area ranged from 3x3 square centimeters to 40x40 square centimeter with the d_{max} depth and proportionately compares variety of radiation amount to the irradiation area of 10x10 square centimeters as shown in Figure 1 b. TMR Table which shows the relationship between TMR and the variation of depth ranged from 0-35 centimeters of the area of 3x3 square centimeters to 40x40 square centimeters as shown in Figure 2

Field Size(cm)	Scp
3x3	0.9021
5x5	0.9485
8x8	0.9840
10x10	1.0000
12x12	1.0146
15x15	1.0315
20x20	1.0560
25x25	1.0691
30x30	1.0780
35x35	1.0836
40x40	1.0880

Position (Cm)	3x3 cm²	5x5 cm²	8x8 cm²	10x10 cm²	12x12 cm²	15x15 cm²	20x20 cm²	25x25 cm²	30x30 cm²	35x35 cm²	40x40 cm²
0.0	0.443	0.45	0.475	0.491	0.508	0.532	0.574	0.606	0.638	0.651	
0.5	0.774	0.777	0.791	0.801	0.81	0.823	0.846	0.862	0.874	0.882	
1.0	0.956	0.956	0.961	0.963	0.966	0.97	0.976	0.979	0.984	0.983	
1.5	1	1	1	1	1	1	1	1	1	1	1
2.0	1.003	1.003	1.003	1.001	1.001	1.001	0.999	0.999	1	0.998	0.998
2.5	0.989	0.991	0.993	0.993	0.992	0.992	0.991	0.99	0.991	0.991	0.991
3.0	0.971	0.976	0.981	0.981	0.981	0.981	0.981	0.981	0.983	0.984	0.983
3.5	0.954	0.961	0.966	0.968	0.97	0.971	0.971	0.972	0.973	0.975	0.974
4.0	0.935	0.945	0.952	0.955	0.957	0.96	0.96	0.962	0.964	0.965	0.965
4.5	0.916	0.927	0.938	0.942	0.945	0.948	0.949	0.952	0.955	0.958	0.956
5.0	0.897	0.911	0.923	0.928	0.932	0.936	0.938	0.941	0.944	0.946	0.946
5.5	0.88	0.895	0.909	0.915	0.919	0.924	0.927	0.93	0.934	0.937	0.936
6.0	0.861	0.879	0.895	0.902	0.906	0.911	0.915	0.92	0.924	0.926	0.926
6.5	0.843	0.861	0.879	0.887	0.892	0.898	0.904	0.91	0.913	0.916	0.916
7.0	0.826	0.845	0.864	0.872	0.878	0.887	0.893	0.899	0.903	0.905	0.905
7.5	0.808	0.828	0.849	0.858	0.865	0.874	0.881	0.887	0.892	0.894	0.895
8.0	0.791	0.812	0.834	0.845	0.852	0.86	0.868	0.876	0.881	0.884	0.885
8.5	0.775	0.796	0.82	0.831	0.838	0.847	0.856	0.864	0.87	0.875	0.875
9.0	0.758	0.78	0.805	0.817	0.825	0.834	0.844	0.853	0.86	0.865	0.866
9.5	0.741	0.763	0.79	0.803	0.811	0.821	0.832	0.842	0.849	0.854	0.856
10.0	0.725	0.749	0.776	0.789	0.798	0.809	0.82	0.83	0.838	0.843	0.844
10.5	0.709	0.734	0.761	0.775	0.785	0.797	0.808	0.819	0.827	0.832	0.833
11.0	0.694	0.719	0.746	0.761	0.772	0.784	0.797	0.808	0.816	0.822	0.824
11.5	0.679	0.704	0.732	0.747	0.758	0.771	0.785	0.796	0.805	0.811	0.813
12.0	0.664	0.689	0.718	0.733	0.744	0.758	0.773	0.784	0.793	0.801	0.802
12.5	0.65	0.675	0.704	0.719	0.731	0.746	0.761	0.772	0.782	0.79	0.792
13.0	0.636	0.661	0.69	0.707	0.719	0.734	0.749	0.761	0.771	0.779	0.782
13.5	0.623	0.646	0.676	0.694	0.707	0.722	0.738	0.751	0.761	0.768	0.771
14.0	0.61	0.633	0.663	0.681	0.694	0.709	0.726	0.739	0.75	0.758	0.761
14.5	0.596	0.621	0.651	0.668	0.68	0.697	0.714	0.728	0.739	0.747	0.751
15.0	0.582	0.608	0.638	0.655	0.668	0.684	0.702	0.717	0.728	0.736	0.74
15.5	0.57	0.594	0.625	0.643	0.656	0.672	0.691	0.706	0.718	0.726	0.73
16.0	0.559	0.582	0.613	0.631	0.644	0.661	0.679	0.695	0.708	0.716	0.72
16.5	0.547	0.569	0.6	0.618	0.632	0.649	0.668	0.684	0.697	0.706	0.71
17.0	0.535	0.558	0.588	0.607	0.62	0.638	0.657	0.674	0.687	0.696	0.7
17.5	0.524	0.546	0.577	0.595	0.609	0.626	0.646	0.663	0.676	0.685	0.689
18.0	0.512	0.535	0.565	0.583	0.597	0.615	0.636	0.653	0.666	0.675	0.679

Figure 1 $S_{c,p}$ Table for 6 MeV energy

Figure 2 TMR Table which shows the relationship between TMR and the variation of depth for 6 MeV energy (Partial)

2. Develop a program to calculate area and length from the digital simulator images.

Develop a program by uses JAVA computer language. Selected test cases radiation area from IAEA TECDOC 1540 guideline for calculated length of the equivalent radiation area in two ways, "Eqs and SQRT" with JAVA language for determine radiation field parameters, "TMR and Sc,p" from beam data

Given that x = the length of x-axis, and y = the length of y-axis

2.1 A command for the length calibration in order to find the scale to use it further.

2.2 A command for the irradiation area calculation when the user has created the irradiation area control line.

2.3 A command for the area calculation for the radiation shielding area after the control line was determined.

2.4 The command for the actual x-axis length calculation after subtracting the radiation shielding area, in which it will be used to calculate for Eqs value.

2.5 A command for the actual irradiation area after subtracting out the radiation shielding area.

2.6 A command for the square root operation of the actual irradiation area calculation after subtracting out the radiation shielding area to calculate for Sqrt value.

2.7 A command for the y-axis range after calculated the actual irradiation area from the equation;

y = (Irradiation area / x)　　　**- equation 1**

2.8 A command for the calculation of Eqs value from the equation;

$$Eqs = Actual\ irradiation\ area/(2x+2y) \qquad\qquad - \textbf{equation 2}$$

2.9 A command to illustrate a side length of Eqs and Sqrt in a text file.

3. The approximation of variable that is used to calculate the radiation monitor unit from radiation beam data measured

Take the data of radiation beam to generate the Fit function, as following;

1. $S_{c,p}$ value in relation to the area, in accordance to this equation;

$$S_{c,p} = 0.072\ln(x) + 0.831 \quad - \textbf{equation 3}$$

Given that, x is a side length of the equivalent irradiation area, which it is derived from the data of the area 3x3 square centimeters to 40x40 square centimeters.

2. TMR value of each area (TMR9d,x)) and the depth of the calculated point from 3.0 centimeter to 20.0 centimeters. When d is the depth value and x is the side length of the equivalent irradiation area. For example;

2.1 The equation of TMR value for the side length of the equivalent irradiation area of 3.0 centimeters; $TMR(d,3) = 0.005x2 - 0.041x + 1.090$ $- \textbf{equation 4}$

2.2 The equation of TMR value for the side length of the equivalent irradiation area of 5.0 centimeters; $TMR(d,5) = 0.00044x^2 - 0.039x + 1.094$ $- \textbf{equation 5}$

2.3 Find the Fit function similarly to the TMR value for the side length of the equivalent irradiation area for various size up to 40 centimeters (Please accept our apology for the unavailability of the equation due to limited space.)

2.4 The Calculation of TMR value

    2.4.1 Use the equation to calculate for TMR value equally to the side length of the equivalent irradiation area.

    2.4.2 When the depth is in between the two equations, the interpolation is needed into a range.

4. The development of the monitor unit calculation program

This part of the program is developed by a Microsoft Visual FoxPro computer language, which the monitor unit can be calculated from the equation (Khan, 2010)

$$MU = \quad PD/(K\ x\ TMR\ x\ S_{c,p}) \qquad - \textbf{equation 6}$$

Given that;

PD	=	The prescript dose
K	=	The amount of radiation of the linear accelerator per monitor unit
TMR	=	Tissue Maximum Ratio
$S_{c,p}$	=	Total scattering factor

5. The group selection of irradiation area to evaluate an effectiveness of the calculation by the program, as shown on the table 1;
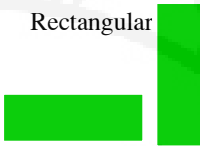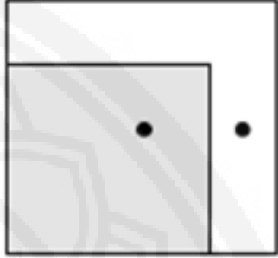
5.1 Select a test case; 1a,1b,1c in order to evaluate an effectiveness of the calculation by the program in a square-shaped area.

5.2 Select a test case; 2a,2b in order to evaluate an effectiveness of the calculation by the program for an elongate field.

5.3 Select a test case 7: Irregular field in order to evaluate an effectiveness of the calculation by the program in an uncertain shape in which the center of the radiation beam were blocked in L-shape.

Table 1 An illustration of the irradiation area in various shapes for a purpose of calculation and measurement of radiation amount in the water phantom

Test case	1a	1b	1c	2a	2b	7
Shape	Square			Rectangular		L-shaped field
Field size (cm.^{2})	5 x 5	10 x 10	25 x 25	5 x 25	25 x 5	Removing 12 x 12 cm.^{2} portion from one corner of 16 x 16 cm.^{2} with block
SAD (cm.)	100					
Gantry (degree)	0					
Test case	1a	1b	1c	2a	2b	7
Depth	3, 5, 10, 15, 20					
Calculation point (Axis)	X = 0					X = 7

6. The calculation of the monitor unit

The calculation has adopted a program that is developed to calculate for MU at a range of 3, 5, 10, 15, 20 cm for the test case as illustrated in Table 1 which is used the prescription dose at 200 cGy.

7. Verify of the MU calculation by the developed program, which compare the amount of radiation calculated and the amount of radiation approximated from the water, with details from the table 1 with the following steps;

(1) Create a irradiation data of the test case 1a, 1b, 1c, 2a, 2b and 7 on the radiation data record and verify system by using MU value of various calculated irradiation area.

(2) Approximate the amount of radiation on each test case with different depth.

(3) Evaluate the error of the amount of radiation that calculated by the developed program

compare to the amount of radiation approximated from the water by using the Relative error for the Test case 1a, 1b, 1c, 2a and 2b with an acceptance criteria of ±2% and by using the Relative normalize error for the Test case 7 with an acceptance criteria of ±3% under the IAEA TECDOC 1540 guidelines.

（4） Analysis of result is as follows;

1） The relative error is the value from the comparison between the amount of radiation from calculation and approximation at the uniform point, as the equation;

$$\text{Error}_1 \ (\%) = 100 \times (D_{cal} - D_{meas})/D_{meas} \quad \text{– equation 7}$$

2） The Relative normalized error at the irradiation central axis while it was blocked is the comparison of radiation amount from calculation and approximation in the open irradiation area at the equivalent depth, as the equation;

$$\text{Error}_3 \ (\%) = 100 \times (D_{cal} - D_{meas})/D_{meas,open} \quad \text{– equation 8}$$

8. **The process of the monitor unit calculation**

Show in Figure 3 and the window of a program in Figure 4;
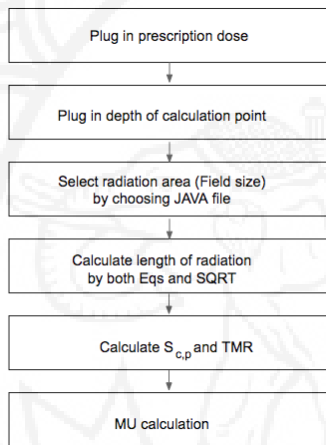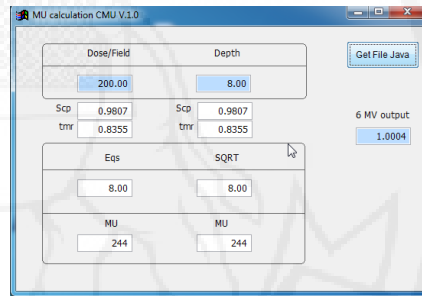

Figure 3 Calculation process

Figure 4 Monitor unit calculation

Results

1. The calculation result for the length of irradiation area from the area interpretation of the group of experimental areas, as shown in table 2 and Figure 5.

Table 2 The calculation result shows the length of irradiation area from the area interpretation of the group of experimental areas.

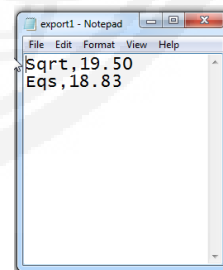| Test case (c.m.)	Length of radiation calculation result result	
	Length by Eqs method	Length by SQRT method
5x5	5	5
10x0	10	10
25x25	25	25
5x25	8.3	11.17
25x5	8.3	11.17
L-shape	11.49	12.01

Figure 5 SQRT and Eqs in text file

2. The comparison result of radiation amount from calculation and from approximation in water of irradiation area test cases group along the IAEA TECDOC 1540 procedure, as shown in table 3, 4, and 5 below;

Table 3 Verified square area test case result

Test case	Depth (cm.)	MU (Eqs)	MU (SQRT)	Measurement dose (cGy)	Relative error (%)
1a	3	215	215	197.96	1.03
	5	232	232	200.12	−0.06
	10	282	282	199.66	0.17
	15	347	347	198.93	0.54
	20	431	431	200.06	−0.03
	3	203	203	197.54	1.25
	5	216	216	200.12	−0.06
1b	10	255	255	200.50	−0.25
	15	305	305	199.17	0.42
	20	370	370	198.51	0.75
	3	190	190	197.81	1.11
	5	199	199	199.73	0.13
1c	10	226	226	199.94	0.03
	15	260	260	198.54	0.73
	20	305	305	197.79	1.12
			Average		**0.67 ± 0.49**

Table 4 Verified rectangular area test case result

Test case	Depth (cm.)	MU(Eqs)	MU(SQRT)	Measurement dose (cGy)		Relative error (%)	
				Eqs	SQRT	Eqs	SQRT
	3	206	202	197.58	193.79	1.23	3.20
	5	220	214	199.39	194.00	0.31	3.09
2a	10	261	251	198.34	190.78	0.84	4.83
	15	315	299	197.85	187.96	1.09	6.40
	20	386	362	198.25	185.59	0.88	7.56
		206	202	197.58	193.79	1.23	3.20
	5	220	214	199.39	194.00	0.31	3.09
2b	10	261	251	198.34	190.78	0.84	4.83
	15	315	299	197.85	187.96	1.09	6.40
	20	386	362	198.25	185.59	0.88	7.56
			Average			**0.92 ± 0.31**	**5.31 ± 1.76**

Table 5 Verified block area test case result

Test case	Depth (cm.)	MU(Eqs)	MU(SQRT)	Measurement dose (cGy)		Relative normalized error (%)	
				Eqs	SQRT	Eqs	SQRT
	3	203	202	196.97	196.00	1.54	2.04
	5	217	215	197.25	195.43	1.39	2.34
7	10	256	253	192.13	189.88	4.10	5.33
	15	306	302	187.86	185.40	6.46	7.87
	20	373	366	187.11	183.60	6.89	8.93
				Average		4.70± 2.33	6.00± 2.80

Result and Discussion

The developed program is divided into two parts, including I) The first part is responsible for acquiring digital data from the digital simulator in order to interpret the irradiation area and the length of the irradiation area, which provide convenience to Physicist and replace an obsolete technology as digitizer and port film. II) The second part is responsible for a calculation for radiation monitor unit, which can provide a quick result that only need to fill in dose/field and depth. The review result of the calculator program with IAEA TECDOC 1540 procedure (TECDOC, 2007). The calculation of the radiation monitor unit in term of Eqs radiation area length, in which the calculation point at the center of radiation beam has the mean percentage error equal to 0.67±0.49 (As shown in table 2) and 0.92± 0.31 (As shown in table 3). The validity is in an acceptance level, however, the calculation of radiation monitor units in term of SQRT lengths has an error beyond the threshold as 0.67±0.49 (As shown in table 2) and 5.31± 1.76 (As shown in table 3), due to the fact that the SQRT lengths are greater than Eqs that makes the arithmetic radiation factors; Sc,p and TMR, greater than the Sc,p and TMR of the Eqs irradiation area lengths, which makes MU of SQRT less than the actual level, as well as, the amount of scattered radiation depends on the Eqs length (Sterling et al., 1964) by using the length and width of the irradiation area for calculation. On the other hand, the SQRT method do not consider the length and width of the area, which cause it to have no correlated variable to the scattered radiation. The review result of the radiation approximation error within the experimental area 7 has an acceptable level of error, which can implies the developed radiation monitor unit calculation program cannot approximate the radiation monitor unit accurately in a case that the shielded experimental area and the calculation point is not at the center of radiation beam (off-axis), although the data collection was done at the center of radiation beam.

Conclusion and suggestion

The calculation for the length of equivalent irradiation area in Eqs term is the only method that can accurately approximate the factors for radiation monitor unit, and we cannot use the length in SQRT term to approximate for the radiation monitor unit. The developed calculation program for the radiation monitor unit can approximate the length of the irradiation area in Eqs term from the visual data from the irradiated area image data from the digital simulator and be able to approximate the radiation monitor unit at the center of radiation beam precisely.

The radiation monitor unit is consisted of the two separate programs. The combination of the two programs into one program will likely to reduce the calculation processes for further convenience. And once in the need of the calculation for the distance from the radiation beam center axis, we could consider apply the adapted Off-axis ratio.

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