Quadratic Regression-based Non-uniform Response Correction for Radiochromic Film Scanners

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1. Introduction

In recent years, several types of radiochromic films have been extensively used for two-dimensional dose measurements such as dosimetry in radiotherapy as well as imaging and radiation protection applications [1]. One of the critical aspects in radiochromic film dosimetry is the accurate readout of the scanner without dose distortion [2]. However, most of charge-coupled device (CCD) scanners used for the optical density readout of the film employ a fluorescent lamp or a cold-cathode lamp as a light source, which leads to a significant amount of light scattering on the active layer of the film. Due to the effect of the light scattering, dose distortions are produced with non-uniform responses, although the dose is uniformly irradiated to the film [3].

In order to correct the distorted doses, a method based on correction factors (CF) has been reported and used [4]. However, the prediction of the real incident doses is difficult when the indiscreet doses are delivered to the film, since the dose correction with the CF-based method is restrictively used in case that the incident doses are already known. In a previous study, therefore, a pixel-based algorithm with linear regression was developed to correct the dose distortion of a flat-bed scanner, and to estimate the initial doses [5]. The result, however, was not very good for some cases especially when the incident dose is under approximately 100 cGy. In the present study, the problem was addressed by replacing the linear regression with the quadratic regression. The corrected doses using this method were also compared with the results of other conventional methods.

2. Methods and Materials

2.1 Non-uniform response

In order to evaluate the non-uniform response of the scanner, beam profile measurements at various dose levels are required, since the response of the scanner depends on the scan position as well as the exposed doses. Thus, the GAFCHROMIC® EBT radiochromic films (batch-number 47277-03I, International Specialty Products, Wayne, NJ, USA) were placed at a depth of 5 cm of a 30×30×30 cm^3 polystyrene solid phantom perpendicular to the beam axis and irradiated from 0 cGy to 307.1 cGy with multi dose steps. The measurements were performed with a 6 MV photon beam from a Varian 6EX linear accelerator.

The irradiated films for evaluation were scanned with the Epson Expression 1680 Pro scanner (Epson Seiko Corporation, Nagano, Japan) of a flat-bed type, which uses a fluorescent light source with a broadband emission spectrum and a linear CCD array detector. The background doses were also subtracted from the results.

The observed dose values monotonically decreased along the horizontal direction, from the center to the edge of the scanner plate for all of the tested dose levels. The difference between the maximum and the minimum pixel values read by scanner gradually increases as the delivered doses get larger. Hence, it is necessary to correct the distortion of dose values by appropriately considering the non-uniform response properties of the scanner.

2.2 Correction of the dose distortion

A quadratic regression-based correction algorithm was designed by considering the response dependency on horizontal pixel position and delivered dose. On each and every pixel, a quadratic curve ($y = ax^2 + bx + c$) was fitted to the points which display the relations between the delivered initial doses and the scanner-read doses. Each of the calculated curves was then applied to the whole horizontal-axis pixel of the distorted image matrix. In this case, it is assumed that the corrected profiles should be equal with the ion chamber profiles because it has been known that an ion chamber is the most stable and accurate detector in profile measurements. The corrected dose profiles were, therefore, compared with those of applying the CF-based method reported from the other study, and those of measuring with an ion chamber.

3. Results and Discussions

3.1 Dose response curve on each pixel

The different trend curves of the scanner responses throughout the pixel position were calculated, as presented in Fig. 1. The dash line indicates the ideal case where the scanner-read values match the delivered doses ($y = x$). Among 576 pixels, the quadratic curve at the 287th pixel where on the center position of the horizontal-axis has a slope of 1.06995. This is most close to the ideal value of 1, whereas those at the edge-sides are significantly different from the ideal case (1.3144 at 5th pixel, 1.3389 at 570th pixel). Thus, it can be seen that the pixel values monotonically overrespond in the horizontal direction, from the center to the edge-sides of the scanner, for all of the delivered doses.

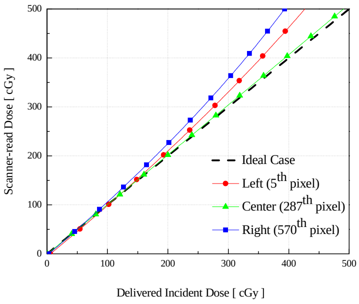

FIG. 1. The quadratic curve of the scanner responses for the delivered incident doses according to the pixel position

3.2 Correction of the dose distortion

The distorted doses decoding from the scanner were separately corrected with the quadratic regression- and CF-based algorithms and compared with the ion chamber profiles. Table I and Figure 2 show the corrected degrees according to a variety of incident dose levels.

Table I: The average profile differences with criteria measured by the ion chamber

Dose (cGy)	Scanner-read dose (%)	Conventional method (%)	This study (%)
8.3	5.59	5.55	4.99
16.6	1.72	5.57	0.45
33.2	3.03	1.91	0.10
49.8	3.19	0.98	0.31
74.7	4.17	2.13	0.18
99.6	5.29	2.18	0.87
124.5	4.86	0.50	0.02
174.3	6.24	1.60	0.49
224.1	7.30	2.26	0.67
307.1	8.15	1.23	0.12

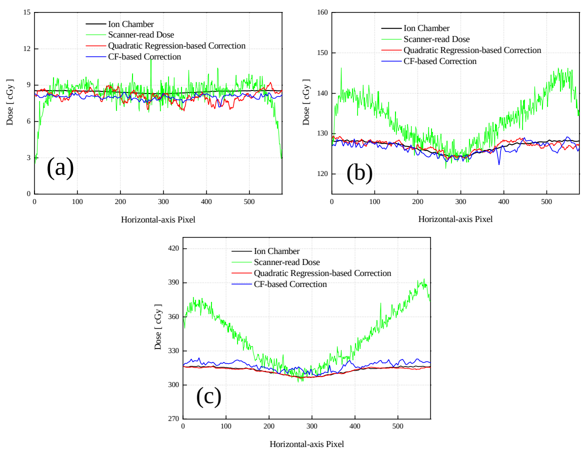

FIG. 2. Comparisons of the horizontal profiles for scanner-read dose, ion chamber, and actual incident dose corrected by applying the quadratic- and CF-based algorithm according to incident dose levels ((a) low (8.3 cGy), (b) mid (124.5 cGy), and (c) high (307.1 cGy) doses).

In case of the very low dose (8.3 cGy), the average profile differences between the ion chamber and the others are shown as 5.59% (scanner-read), 5.55% (CF-based correction), and 4.99% (quadratic regression-based correction). It is recognized that the dose correction using any methods is challenging, as the deviation of the sensitivity among the individual films is very high in low dose region. However, the dosimetric error in comparison with criteria measured by the ion chamber was reduced within 1% using quadratic regression-based method in the whole dose region except for the very low dose (under approximately 10 cGy), while those of using CF-based method agreed within 3% in the dose region more than about 2-30 cGy.

4. Conclusions

In order to correct the non-uniform response of flatbed type scanner for a radiochromic film, a quadratic regression-based correction algorithm was designed and applied to the distorted film matrix. This method could reduce the dosimetric error within 1% in comparison with criteria in the tested cases, except for the very low dose less than approximately 10 cGy.

The quadratic regression-based correction algorithm is more useful than the conventional CF-based correction method and pixel-based algorithm reported in the previous study, considering the prediction of the incident doses and the high accuracy in the extensive dose area. Therefore, this correction method with enhanced accuracy will promote the applicability of the radiochromic film to various industrial cases.

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