RANGE VERIFICATION SYSTEM USING SCINTILLATOR AND CCD CAMERA SYSTEM

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Abstract

For the daily QA of the energy scanning delivery, quick and easy range verification system is required. In this work, we have developed range verification system using scintillator and CCD (charge-coupled device) camera. From the comparison of the several methods, edge detection method is best for range detection. Accuracy of range detection for the system is within the 0.2 mm. Reproducibility of the range is within 0.1 mm. Our range check system has shown to be capable of quick and easy range verification with sufficient accuracy.

INTRODUCTION

At NIRS, three-dimensional irradiation with carbon-ion pencil-beam scanning has been performed from 2011 [1]. We have been commissioning the irradiation method that employs more than 200 multiple beam energies supplied by synchrotron instead of the energy degraders [2]. Since carbon ion deposits most of their energy in the last final millimeters of their trajectory, the accuracy of the beam energy/range is required for carbon ion treatment especially for using scanning method. ICRU78 recommend checking the range constancy for daily QA. Recommended relative accuracy of range measurements is less than 0.5 mm [3].

In the current daily QA at NIRS, Few-points depth dose measurement using ionization chamber is employed for range verification. It takes about 1 minute for a measurement of one energy beam. In order to apply the range check for multiple energy beams, quick and easy range verification system is required. The purpose of this work is to develop range verification system using scintillator and CCD camera and to estimate the accuracy of the range verification using the system.

MATERIALS AND METHODS

Experimental Setup

The scintillator and CCD system is shown in Fig. 1. The system is consisted of a scintillator block, CCD camera, and opaque (black) box. Light distribution is detected by CCD camera through a mirror. The optical path length between the scintillator and lens is 400 mm. The system was placed on the treatment couch. The center of the scintillator was placed at isocenter.

A EJ-200 plastic scintillator block was selected for pure tranceparent block, similar density with human body, and matching wavelength of maximum emission for CCD camera. The size of cylindrical scintillator block was 200 mm diameter ×100 mm thickness. For shading the light from the treatment room, the scintillator was wrapped by light blocking sheet. The CCD camera (Type BU-41L, 1360x1024 pixels, Bitran Corp., Japan) was installed on the light-shielding house. The spatial-resolution of the system is 0.2 mm/pixels.

Image Acquisition

All measurement was performed at fixed vertical beam line. Total 131 energy carbon beams with mini ridge filter that were in the range from 56 to 332 MeV/n were measured sequentially. The data acquisition of the CCD camera was synchronized with irradiation. We measured pencil-beam having intensities between 8×10^7 and 1.6×10^8 particles per second. Measurement time is 0.1 sec for all energy.

Image Processing

Measured two-dimensional images were processed by in-house program developed by c++. The workflow of image processing is shown in Fig. 2. After the background correction and median filter, projection on one-dimensional axis is performed.

Range Scaling Factor

The common reference point of range is distal 80% of the dose distribution. However the system measures the range not with the dose distribution but with the light distribution. Archambault *et al*. concluded that the distal 80% minimized discrepancies between expected and measured ranges for proton beam [4]. Fukushima *et al*. also use 80% and obtained great result [5]. To our knowledge, there is no published report of clinical carbon range measurement with scintillator. In order to select the best reference point on a light distribution, the authors compared two range detection methods using several parameters.

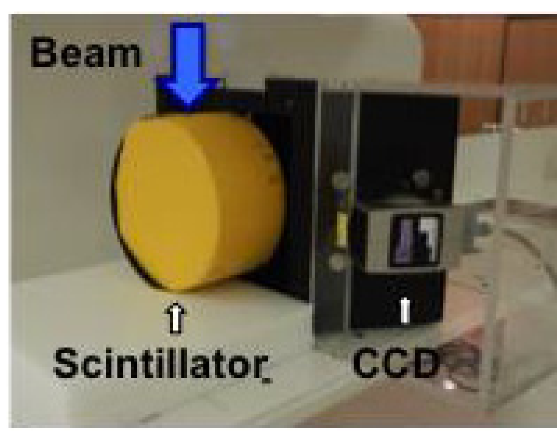

Figure 1: Layout of the scintillator and CCD system.

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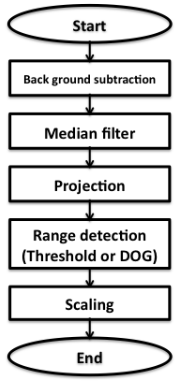

Figure 2: Workflow of the image processing.

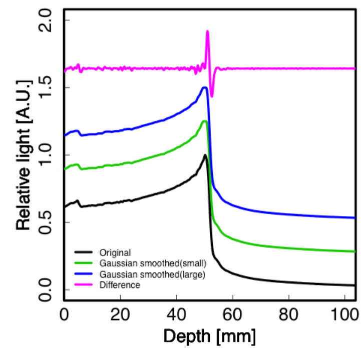

Figure 3: Instruction of the DOG method.

One is threshold method (TH); the threshold positions set by 30, 50, 60, 70, 80, and 90% of maximum value on the projected line are identified. The other is difference of Gaussian (DOG) method; DOG method is widely used in edge detection field instead of Laplacian filter [6]. Using DOG method, range position is determined by zero-crossing position in the difference between small-Gaussian smoothed image and large-Gaussian smoothed images. Sigmas for small and large Gaussian are 1 and 1.5 pixels respectively. As shown in Fig. 3, only the high-frequency edge position is enhanced when relative small sigma is used. In this work, range-scaling factor is applied. The Range Shifter (RSF) that gave us the least deviation from the expected relative range for all RSF thickness is then used for all range measurements.

RESULT

Depth Brightness Distribution

Fig. 4 shows the example of the depth brightness distribution acquired with the system. Measurement time was about 5 seconds for one energy beam. Peak-plateau ratio was small due to quenching effect and absorption of the light within the scintillator block.

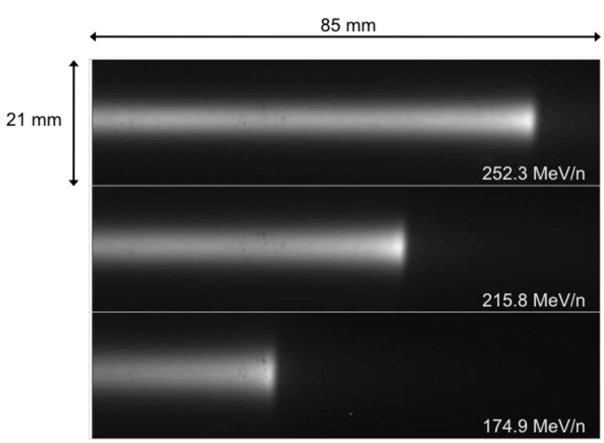

Figure 4: Example of the depth brightness distribution acquired with CCD camera.

Range Scaling Factor Using Range Shifter

The RSF plates with thickness from 0.5 to 4 mm was inserted upstream of the system. Reference depth dose distribution measured by ion chamber and depth brightness distribution with/without RSF measured by the system were shown in Fig. 5. All curves were normalized at highest point. As it can be seen, the brightness distribution was clearly separated by the RSF thickness. The relative range was determined by range between the without RSF and with RSF. Comparison of the relative range between RSF thickness and relative range determined by DOG method was shown in Fig. 6. Relative range differences from the expected range were very small. Standard deviation was less than 0.05 mm for all measurements. Summary of mean difference and standard deviation for all range detection methods were listed in Table 1. It was found that differences of relative range are very small with many method but using DOG method minimized differences between expected and measured ranges.

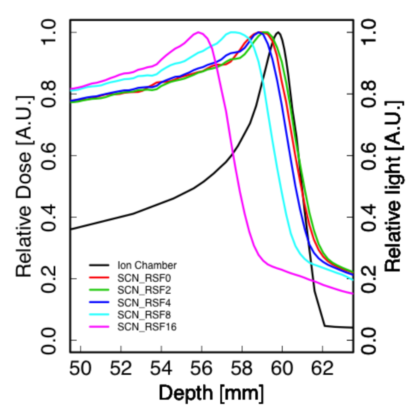

Figure 5: Comparison between the reference depth dose measured by ionization chamber and relative light output shifted by RSF.

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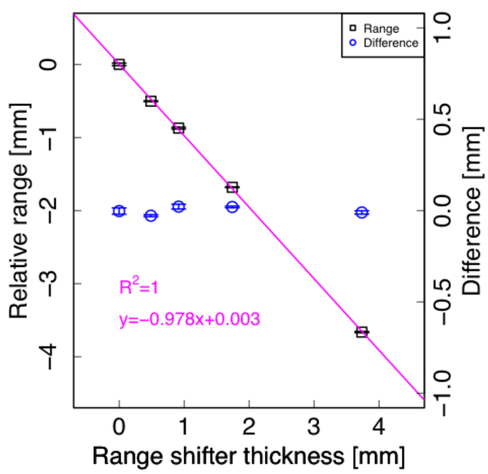

Figure 6: Comparison of the relative range with range shifter thickness.

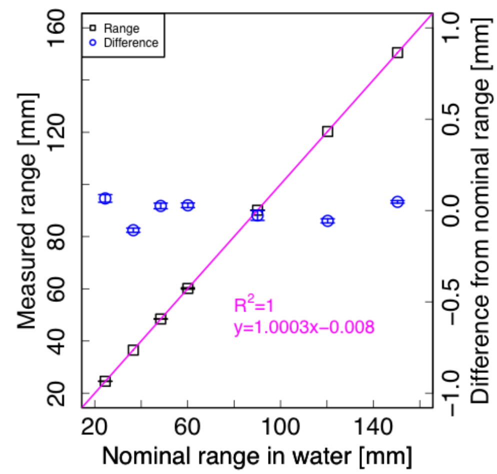

Figure 7: Measured range using DOG method and difference from nominal range.

Table 1: Comparison of the Difference Between RSF Thickness and Measured Relative Range Using Threshold and DOG Method.

Method	Mean Difference [mm]	Standard deviation [mm]
TH_30%	0.003	0.033
TH_50%	0.002	0.030
TH_60%	0.002	0.029
TH_70%	0.001	0.028
TH_80%	-0.001	0.037
TH_90%	0.000	0.043
DOG	0.000	0.022

Table 2: Comparison of the Difference from Nominal Range Changing Using Threshold and DOG Method.

Method	Mean Difference [mm]	Standard deviation [mm]
TH_30%	0.015	0.296
TH_50%	-0.011	0.078
TH_60%	-0.011	0.071
TH_70%	-0.011	0.068
TH_80%	-0.014	0.072
TH_90%	-0.018	0.078
DOG	-0.003	0.055

Depth Measurement

Comparison of the nominal carbon range in water and the range measured in the scintillator system with DOG method is shown in Fig.7. The pencil beam with range in water between 24 mm and 150 mm were employed. Summary of mean difference and standard deviation for all range detection methods were listed in Table 2. The measured range is closed to the nominal range in water for all energies. It was found that differences of range were very small with many method but using DOG method minimized differences between expected and measured ranges. The mean difference between the nominal and the measured with DOG method range -0.003±0.055 mm (1 SD). The maximum discrepancy was 0.108 mm.

CONCLUSION

In this work, range verification system using scintillator and CCD camera has been developed. We have shown that the range of carbon pencil beam can be determined with subminiature accuracy with some image processing. We have found that Edge detection method (DOG) is minimized discrepancies between expected and measured ranges for carbon beam.

It was supposed to be a result of the change of shape due to quenching effect. Since the system determine the range with short time and sufficient accuracy, it seems be that the system has potential to play the daily range check system.

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