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3D Dose Reconstruction Based on the EPID

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Abstract. The increasing complexity of modern radiation therapy techniques has increased the need for validation of the actual dose of radiation received by patients, including plan validation before treatment and in vivo dose validation. EPID has the potential for in vivo three-dimensional dose validation, EPID can not only validate the accuracy of tumor target dose, but also assess the harm extent of the dose to the surrounding organ. This paper summarizes some research progress in our study: 3D dose reconstruction based on the EPID. In the simulations, the source intensity was derived from the EPID data, which was very close with original source intensity. Finally the 3D dose distribution was calculated by DOSXYZnrc.

Research Background

According to an article published by Wan-qing Chen in 2016[1], there were about 4.292 million new cases of cancer and 2.84 million deaths in China in 2015. The article points out that cancer has become the leading cause of death in China, and the morbidity and mortality are still rising. At present, the treatment of cancer mainly depends on surgery, radiotherapy and chemotherapy. Radiation therapy is an important method of cancer treatment and its goal is to maximize the radiation dose to tumor region (target area) to kill the tumor cells while protect the normal tissues and organs from unnecessary radiation. The increasing complexity of modern radiation therapy techniques has increased the need for validation of the actual dose of radiation received by patients, including plan validation before treatment and in vivo dose validation.

With the continuous development of EPID, especially in recent years, the amorphous silicon EPID is widely used, whose high speed imaging, large area imaging, high resolution imaging, digital format storage, tolerance to high dose and other advantages inspire people to continue to expand its scope of application. EPID has the potential for in vivo three-dimensional dose validation, which can combine the transmission dose obtained by EPID with cone beam CT (MV CBCT) to reconstruct the three-dimensional dose distribution map containing patient anatomical information. EPID can not only validate the accuracy of tumor target dose, but also assess the harm extent of the dose to the surrounding organ. EPID can detect dose differences caused by patient related errors, such as position errors or errors caused by weight change. The deviation of the portal location, shape and dose distribution of the irradiated field relative to the target area can be corrected or optimized in time to ensure the accuracy of the target treatment and the optimization of the individual therapy program. Therefore, the EPID system now used in MV level X ray is not the traditional imaging equipment, which has the function of dose detection. It has become the prototype of dose guided radiotherapy equipment.

There are generally two kinds of methods to achieve patient dose verification, one is forward algorithm and the other is inverse algorithm[2]. The reverse verification algorithm is that the EPID capture the output dose image firstly, and calculate the dose distribution inside the body reversely, then compare the dose distribution with the result calculate from TPS. So the reverse verification algorithm can verify the dose distribution of target field. The inverse algorithm is more practical in the verification of three-dimensional dose distribution and in vivo dose guided radiotherapy[3].

Accurate three-dimensional dose reconstruction is the key to achieve dose guided radiotherapy, and many overseas research institutes have conducted extensive studies on it[4-6]. This article will summarize some research progress in our study of medical dose-guided radiotherapy--reconstruct the 3D dose distribution in 3D model. The scattering effects of the EPID and phantom (patient) are taken into account in the reconstruction model.

Introduction of Algorithms

The purpose of 3D dose reconstruction is to reconstruct dose distribution in 3D model by measuring the radiation intensity distribution. The basic idea is to deduce the intensity distribution of accelerator source, and then use the source intensity as the input of dose calculation engine to calculate the 3D dose distribution in the phantom or patient. The flowchart of algorithm is as follows:

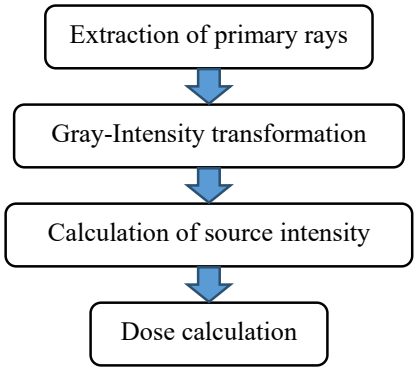


Figure 1. Flowchart of algorithm.

Extraction of Primary Rays

High energy rays will interact with the substance when passing through the body in the radiotherapy. A part of the rays will be absorbed by the phantom and convert to be phantom dose. Another part of the rays will forms gray scale image by irradiating on the EPID through the phantom, and the penetrating rays can be divided into primary rays and scattering rays. The primary rays are the rays directly irradiating on the EPID, and the rays that interact with the phantom and then irradiate on the EPID in a scattering way are called scattering rays. The scattering rays are not only scattering from the body but also the head of accelerator and the EPID itself etc. Therefore, the gray scale response value of point (i, j) on the EPID detector should contain the primary rays' gray scale value G_{ij}^{p} and the scattering rays' gray scale value G_{ij}^{s}, their relationship is as follow:

$$G_{ij}^{EPID} = G_{ij}^{p} + G_{ij}^{s}. \tag{1}$$

The primary rays' gray scale value G_{ij}^{p} can be obtained by

$$G_{ij}^{p} = G_{ij}^{EPID} \otimes \widetilde{K}_{ij}^{-1}. \tag{2}$$

Where $\widetilde{K}_{ij} = \delta(r_{ij}) + K_{ij}, \delta(r_{ij})$ represents δ function, r_{ij} represent the distance between the point (i, j) and the axis (Off-axis distance). K_{ij} is scattering kernel function. In this paper, we use the radiation symmetric Gaussian kernel function to describe the scattering kernel function[7].

Gray-Intensity Transformation

The gray response value of primary rays will not affected by the portal size and shape. Establishing the calibration relationship between gray scale and intensity is the premise of measurement and verification of radiation dose.

G_{ij}^{p} is the gray response value of primary rays at point (i, j). In other words, G_{ij}^{p} is the accumulated pixel value at the point (i, j) after the correction[8-10]. I_{ij}^{p} is the primary rays' intensity value corresponding to its gray scale at point (i, j) on the EPID. They have the following relationship :

$$I_{ij}^{p} = G_{ij}^{p}.CH_{ij} \quad (3)$$

CH_{ij} is the gray-intensity transformation matrix. The calibration relationship between gray scale and intensity can be calculated by comparing the gray scale on the EPID and the off-axis distribution of source intensity which can be calculated from 3D water tank or ionization chamber through experiments[11].

Calculation of Source Intensity

Intensity of the primary rays follows the exponential decay law when it penetrates the phantom. As the organs or tissues of human are composed of plenty of material compositions with different densities, the absorption coefficients for X-ray inside the phantom are different. t_{ij} represents the equivalent water thickness of the radiation path. The path length that rays passing through the phantom can be converted into the thickness of the water phantom according to the formula as follows:

$$t_{ij} = \rho_{\text{water}}^{-1} \cdot \int_{source}^{\text{detector}} \rho_m(l)dl \quad (4)$$

Where ρ_m is the electron density of mediums in the penetrating path, and ρ_{water} is the electron density of water.

The curve of CT number to relative electron density is not linear within the range of tissue density[12]. The conversion formula is shown below[13]:

$$\rho_m = 0.001N_{CT} \qquad 0 < N_{CT} < 1000$$

$$\rho_m = 0.4324 + 5.676\text{x}10^{-4} N_{CT} \qquad 1000 < N_{CT} < 2500 \quad (5)$$

Where N_{CT} is the normalized CT number.

The source intensity I_{ij}^{p0} can be calculated by formula 6:

$$I_{ij}^{p0} = I_{ij}^{p}.e^{\mu_{ij}.t_{ij}} \quad (6)$$

In our study, we use the quadratic exponential function to calculate attenuation coefficient:

$$\mu_{ij}t_{ij} = -\alpha(r_{ij})t_{ij} + \beta^2(r_{ij})t_{ij}^{\ 2} \quad (7)$$

Where α and β are rotationally symmetric at the center axis. Due to attenuation coefficient is almost linear within finite off-axis distance, we adopt the coefficient value of the point where the off-axis distance is zero according to RenQiang's attenuation coefficient calculation experiment[12]in order to facilitate the calculation.

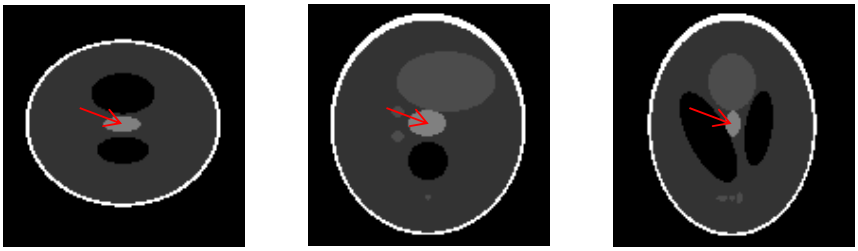
Dose Calculation

Our method is to use the Monte Carlo software DOSXYZnrc to calculate the spatial dose distribution directly with the input data of the phantom and source intensity information. DOSXYZnrc is a general purpose software for calculating the dose distribution in EGSnrc. It can simulate the transmission of photons and electrons in vivo and record the energy deposited in voxels.

Simulation

Phantom

In order to simulate a head tumor radiation environment, we made a 3D Sheep-Logan model with an extra ellipsoidal tumor model inside. The phantom's size is 128x128x128. See figure 2:

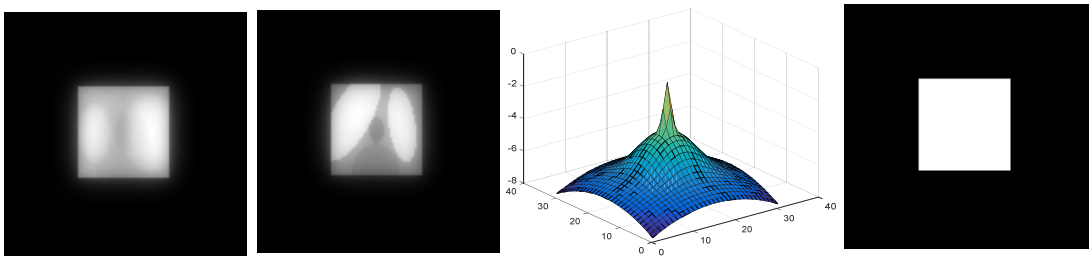


(a) (b) (c)

Figure 2. Middle slices in three different coordinate directions (a: X-axis, b:Y-axis, c:Z-axis; The red arrows indicate the location of the tumors).

Simulation of EPID Projection Data

We made a square field as the source portal, and the source intensity in the field is uniform, see figure 3(a). After considered attenuation and scattering, we used MATLAB R2016a to simulate the EPID data. See figure 3(c and d):

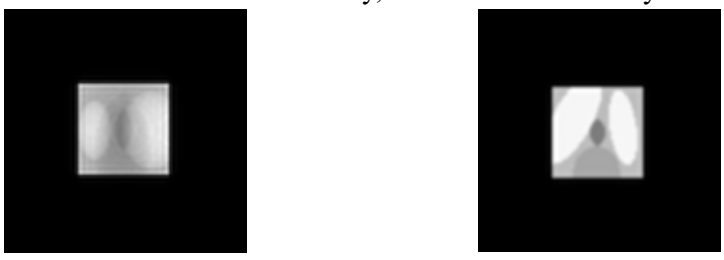


(a) (b) (c) (d)

Figure 3. a: Source intensity in one direction, b: Scattering kernel, c: Simulated EPID data(projection angle is 90°), d: Simulated EPID data (projection angle is 180°).

Calculation of Source Intensity

According to formula 2, we can remove the scattered influence and obtain the primary rays' intensity information. The results are shown in figure 4. According to the formula 6, the source intensity can be derived from the deconvolution results (see figure 5). By compared the original source intensity with the calculated source intensity, we could see that they are very close.



(a) (b)

Figure 4. EPID data after deconvolution, a: projection angle is 90°, b: projection angle is 180°.

(a) (b)

Figure 5. Source intensity by calculation ,a: projection angle is 90°, b: projection angle is 180°.

3D Dose Reconstruction

We used the Monte Carlo software DOSXYZnrc to calculate the 3D dose distribution. Firstly, the phantom model was imported into DOSXYZnrc, where the model size is 32cm*32cm*32cm and each voxel size is 1cm*1cm*1cm. The source skin distance (SSD) is set to 95cm, and the field size is 10*10cm. Then the 3D dose distribution can be calculated by DOSXYZnrc. See figure 6.

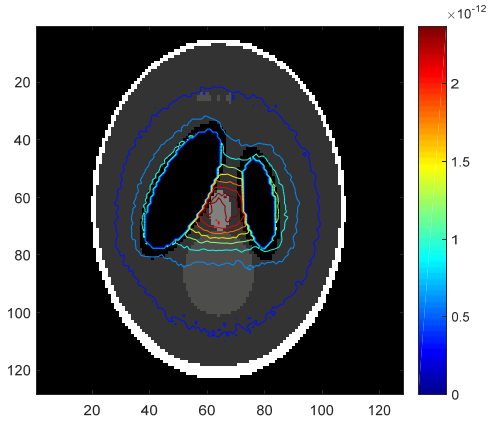


Figure 6. A slice of the 3D dose distribution.

Conclusions

This paper summarizes some research progress in our study -- 3D dose reconstruction based on the EPID. In the simulations, the source intensity was derived from the EPID data, which was very close with original source intensity. Finally the 3D dose distribution was calculated by DOSXYZnrc. The next work is to adjust the parameters and convolution kernel function, optimize the algorithm to improve the accuracy of dose calculation and reduce the calculation time.

Acknowledgements

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References

[1] Chen W., Zheng R., Baade P.D., et al. Cancer statistics in China, 2015 [J]. CA: A Cancer Journal for Clinicians, 2016, 66(2): 115-132.

[2] Yan-Ze Sun. Study on Dosimetric Verification System based on Amorphous Silicon Flat Panel Detector [D]. Soochow University, 2012.

[3] Rui-Fen C., Yi-Can W., Xi P., et al. Multi-objective optimization of inverse planning for accurate radiotherapy [J]. Chinese Physics C, 2011, 35(3): 313.

[4] Mans A., Remeijer P., Olaciregui-Ruiz I., et al. 3D Dosimetric verification of volumetric-modulated arc therapy by portal dosimetry [J]. Radiotherapy and oncology, 2010, 94(2): 181-187.

[5] van Elmpt W., Petit S., De Ruysscher D., et al. 3D dose delivery verification using repeated cone-beam imaging and EPID dosimetry for stereotactic body radiotherapy of non-small cell lung cancer [J]. Radiotherapy and Oncology, 2010, 94(2): 188-194.

[6] Van Zijtveld M., Dirkx M.L.P., de Boer H.C.J., et al. 3D dose reconstruction for clinical evaluation of IMRT pretreatment verification with an EPID [J]. Radiotherapy and Oncology, 2007, 82(2): 201-207.

[7] Pasma K.L., Heijmen B.J.M., Kroonwijk M., et al. Portal dose image (PDI) prediction for dosimetric treatment verification in radiotherapy. I. An algorithm for open beams [J]. Medical physics, 1998, 25(6): 830-840.

[8] Louwe R.J.W., McDermott L.N., Sonke J.J., et al. The long-term stability of amorphous silicon flat panel imaging devices for dosimetry purposes [J]. Medical physics, 2004, 31(11): 2989-2995.

[9] McDermott L.N., Louwe R.J.W., Sonke J.J., et al. Dose–response and ghosting effects of an amorphous silicon electronic portal imaging device [J]. Medical physics, 2004, 31(2): 285-295.

[10] Dutreix A. Monitor unit calculation for high energy photon beams [M]. Garant Publ., 1997.

[11] Renner W.D., Norton K.J., Holmes T.W. A method for deconvolution of integrated electronic portal images to obtain fluence for dose reconstruction [J]. Journal of Applied Clinical Medical Physics, 2005, 6(4).

[12] Guo-Sheng Feng, Yuan Liang, Dan-Ling Wu, Yan-Rong Hao, He-Ming Lu, Jia-Xin, Chen, Chao-Long Liao, Ying Mo, Yi-Hang Huang. Impact factor of relationships between CT value and relative electron density for treatment planning system [J]. Chinese Journal of Radiation Oncology, 2012: 281-284.

[13] Gang Song. Development of RBM Dose Engine for Accurate Radiotherapy Planning System [D]. Hefei University of Technology, 2005.