

Algorithms for Calculation of DRRs for Different Accelerator Voltages and Tools for Work with DRRs

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Abstract - The aim of this study was to develop algorithms for simulation of DRR calculation for different accelerator voltages. We also developed a number of useful tools for an application of DRRs in modern brachytherapy treatment planning.

Index Terms – DRR (digitally reconstructed radiograph), brachytherapy, catheters, computed tomography

I. INTRODUCTION

Modern brachytherapy treatment planning is image based and frequently used imaging modality is CT scanning. We use the CT-data set to form the three dimensional volumetric data set, whose each voxel is characterised with the characteristic CT-number given in Hounsfield units (HU). From this volumetric data set we further calculate DRRs defined with a number of parameters selected by user. Clinical use of such developed DRRs is presented next.

II. MATERIAL AND METHODS

A. Calibration of CT scanning machine

First step in the process of DRR calculation was to make calibration of our CT scanning machine, Somatom Plus 4 CT scanner[♦], and to acquire the curve "Relative electron density ~ Hounsfield numbers"^{1,2}. This calibration was made with using the 33 cm diameter phantom, "RMI Electron Density Phantom model 465"[♦]¹⁻³. The aim was to establish the relationship between the electron density of various tissues and their corresponding CT number. This phantom has twenty 2.8 cm-diameter holes, into which 6 rods made of commercially available plastics and 11 rods simulating different tissues with known elemental composition and electron densities, were inserted^{3,4}. The remaining three rods are made of solid water, the same material as the bulk of the phantom.

As the calibration of the CT scanning machine is done, we

establish the relationship between the relative electron density of material and its HU:

$$r_i = \begin{cases} \text{if } HU_i \in [7, 58] & 0.00098 \times HU_i - 0.994, \\ \text{if } 7 < HU_i \leq 58 & 0.00185 \times HU_i - 0.975, \\ \text{if } HU_i > 58 & 0.00051 \times HU_i - 1.05 \end{cases} \quad (1)$$

B. Look-up tables

Relative electron density and an elemental compound of different human tissues is well known from literature⁵⁻⁷. We divide the whole range of HU values that our treatment

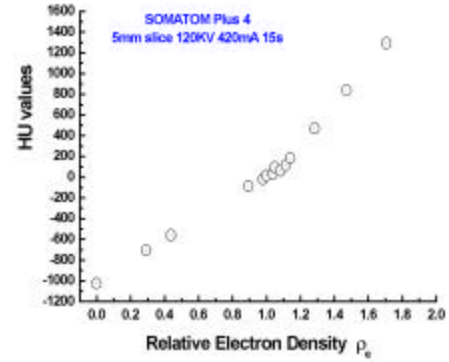


Fig. 1. A calibration curve, relating CT number (HU) to electron density (ρ_e).

planning system use: $[-1500; 4500]$ HU, in 23 sub-ranges. These sub-ranges are defined with the calculated HU values of 23 calibration materials and human tissues of known electron density. Using the XCOM⁸ program, we next calculate the linear attenuation coefficients of those 23 materials for 11 different accelerator voltages (0.05, 0.075, 0.10, 0.125, 0.15, 0.30, 0.37, 1.25, 6.0 and 12.0 [MeV]), from their known elemental composition^{1,2}. After that, the linear attenuation coefficient for the energy X , for the material of the HU number HU_x which belongs to one of 23 sub-ranges: $[HU_a, HU_b]$, is calculated by the linear interpolation from the linear attenuation coefficients of the known tissues a and b for the same accelerator energy.

After that, look-up tables are formed of the pairs $(HU_i, \mu_{E,i})$ for all selected energies and HU numbers which belong to the range $[-1500; 4500]$ HU. This look-up tables are used in the DRR calculation algorithm.

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[♦] Radiation Measurements Inc.

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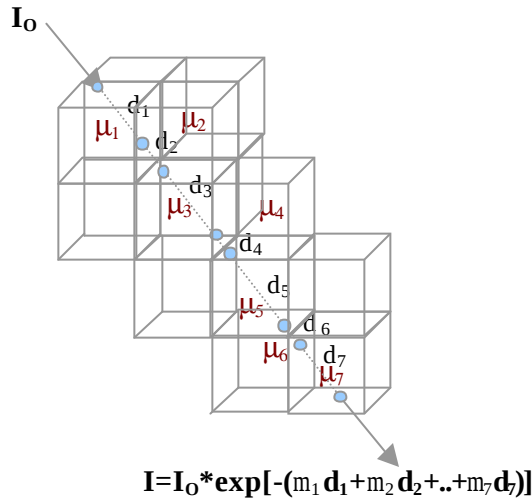


Fig. 2. Ray tracing process presentation. I_0 is the initial ray energy and I is an attenuated ray energy after the ray tracing through the volumetric data set is done. d_i are distances between the ray entrance and exit point in the voxel i , and μ_i is the linear attenuation coefficient of voxel i .

C. User Defined Parameters

Before the process of DRR calculation starts, user need to select a number of available parameters which are used in the DRR calculation algorithm^{1,2}. Those are: (a) DRR calculation method (*pseudo-simulation* or *splatting* method), (b) number of DRRs (one or two), (c) area of calculation (whole CT data set, region within the body contours, user defined region), (d) volumetric data resolution in x, y and z direction, (e) DRR image resolution, (f) accelerator voltage, (g) gantry angle, focus-film and focus-axis distance, (h) DRR range filters (anatomical: bone, fat, soft tissue, and catheter filters: plastic and metallic).

D. Pseudo-simulation of DRR calculation

Pseudo-simulation algorithm for the DRR calculation calculates the attenuation of the ray coming from an accelerator source and passing through the volumetric data set onto the DRR image plane. Simplified process is presented in Fig. 2. Resulting images are shown in Fig 3.

E. Splatting technique

Basic splatting algorithm used here for the DRR calculation is presented elsewhere⁹⁻¹² and we will not discuss it here.

F. Tools used in work with DRRs

Whenever the set of patient CT-data is available, DRR can be used instead of the classical radiological film. Beside a number of advantages of this method which are numbered in **Conclusion**, we developed very helpful tools for work with DRRs. Some of those are: (a) projection and display of target and organ-of-interest contours on DRR images, (b) catheter reconstruction tools from the two isocentric DRRs which is "helped" with the matching and navigation algorithms between the two DRRs, (c) catheter projection on DRR (if

they are already reconstructed), (e) magnification of the chosen areas, (f) DRR image processing to produce the best image quality, (f) absence of the noise caused by scattering, (g) navigation tools (between the (i) 3D volume / any CT slice to DRR image, (ii) between two DRRs), (h) ruler which shows distances in a real dimensions, (i) patient position correction by matching the portal image and one DRR image produced for the same accelerator energy and geometric parameters, (j) DRR range filters (anatomical: bone, fat, soft tissue, Fig. 4, and catheter filters: plastic and metallic), Fig. 5, etc.

G. Catheter reconstruction from two DRRs

Two different reconstruction methods are developed for the catheter reconstruction from two isocentric DRR images¹³. First is the one-to-one reconstruction method, which lead user through the reconstruction process with a help of the navigation tools between two DRRs. The second is the generalized polynomial method which does not require an user knowledge about the catheter pairs, neither their corresponding points on two DRRs.

III. RESULTS AND DISCUSSION

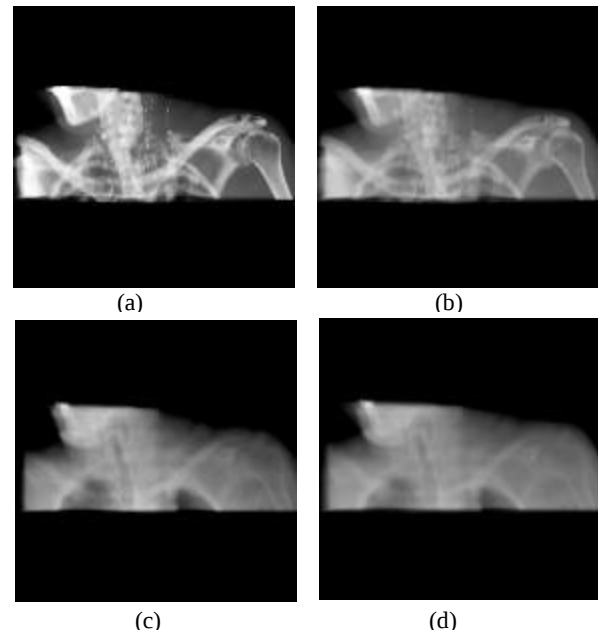


Fig. 3. DRRs calculated for the different accelerator energies: (a) 0.050 MeV, (b) 0.150 MeV, (c) 1.25 MeV and (d) 6.0 MeV.

Our DRR algorithm was tested in everyday clinical practice. It significantly shortened the process of treatment planning, simplifies it for the user and make the whole process much more accurate and user friendly. The most important thing is that there is no additional patient irradiation which occur while taking the classic radiological films.

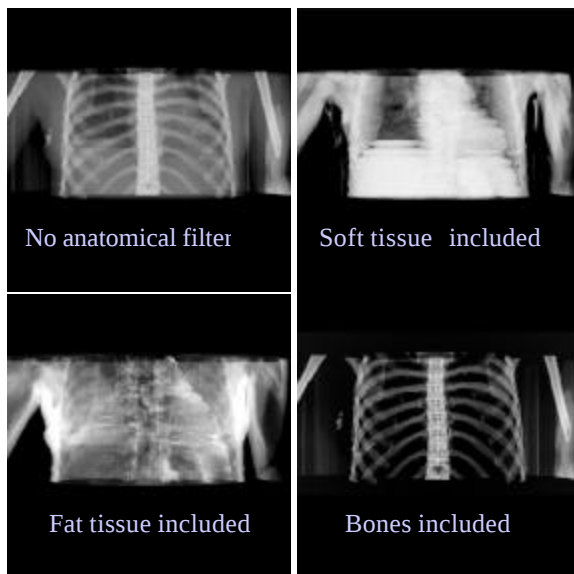


Fig. 4. Example of use of the anatomical filters in the DRR calculation process.

IV. CONCLUSION

This approach has a number of advantages against the work with a classical radiological films:

- (i) There is no additional patient irradiation that enables calculation of necessary number of DRRs to find the two best views for the process of catheter reconstruction.
- (ii) Use of *anatomical* and *catheter filters* enables reconstruction of the catheters that would otherwise be entirely or partly obscured by bones and soft tissue.
- (iii) No need for the radiological film acquisition and digitalization that significantly speeds up the process of catheter reconstruction.
- (iv) Possible patient motion during the CT slice acquisition is insignificant compared to the motion present between the two radiological films acquisition.
- (v) There is no need for matching between two DRRs, as in the case of radiological films as DRRs are produced from the same volumetric data set.

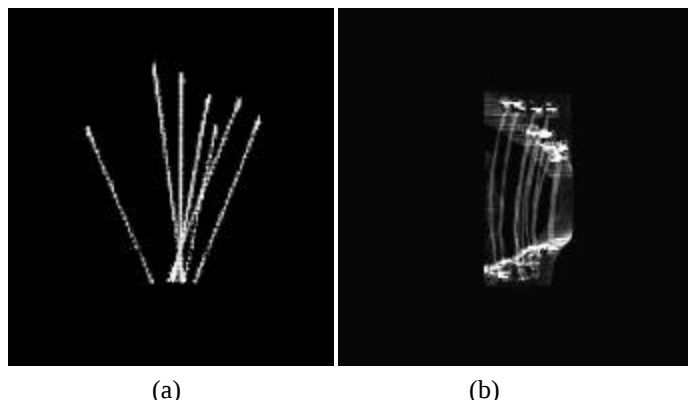


Fig. 5. Example of the use of catheter filters: (a) metallic and (b) plastic catheters projected on the DRR image plane (prostate and breast cancer). All other information is rejected.

(vi) Simple solutions for the (usually) ill defined cases which can occur during the catheter reconstruction from radiological films.

(vii) Simple patient-position correction by matching of one portal image and DRR image calculated for the same energy.

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