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EVALUATION OF CHANG'S ATTENUATION CORRECTION METHOD IN THE ACS SOFTWARE

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ABSTRACT

In patient-specific treatment planning systems the internal dosimetry procedures calculates the spatial dose distribution (3D) within the patient. These procedures were performed using Monte Carlo codes with photon and electron transport simulation. Such systems use patient specific data giving a more realistic anatomical model than the simple geometrical models used habitually. CT images can be used to provide this anatomical information. It is also essential a prior knowledge of activity distributions within the patient which can be obtained from SPECT images. At the moment, this methodology is under development in the Nuclear Engineering Center at IPEN. In order to obtain the functional information the ACS (Attenuation Correction SPECT) software has been developed. It performs the attenuation correction in SPECT images through Chang's method first order. Finally, the software creates the activity distribution within the patient that will be used for the Monte Carlo simulation for dose assessment. The present paper describes the development of the ACS software and its validation.

1. INTRODUCTION

Nuclear medicine has been widely used in cancer diagnosis, however, it is seldom used in therapy. Recently, with the discovery of new therapeutic agents for radioimmunotherapy, for example, monoclonal antibodies, this area has lately undergone high growth. The basic goal of radionuclide therapy is to deliver a given radiation dose which is lethal to the tumor tissue without harming the normal tissue [1]. Due to the high dose used in cancer therapy it is very important to quantify it accurately in order to avoid a high-dose rate in healthy tissues [2].

Modern systems of internal dosimetry have used medical images and Monte Carlo radiation transport codes to provide the dose distribution within the patient. Computed Tomography (CT) or Magnetic Resonance Imaging (MRI) images are used to obtain more realistic information of the patient's body. Functional imaging as Single Photon Emission Computed Tomography (SPECT) or/and Positron Emission Tomography (PET) are used to provide the 3D activity distribution within the patient. Finally, these information are used as an input data for a Monte Carlo radiation transport code which will perform dose calculation [3-7].

A dosimetry system has been developed by a medical physics group at the Nuclear Engineering Center of IPEN (Research Institute Energy and Nuclear). To provide the information contained in the CT images it was built the ICCT (Image Converter Computed

Tomography) software [8]. It converts CT images in tissue parameters (mass densities (ρ) and elemental weights (ω_i)). In order to obtain the functional information it was developed the ACS (Attenuation Correction SPECT) software which creates the activity distribution within the patient. The obtained information becomes input data for the SCMS [6] software which supplies the input file to Monte Carlo radiation transport code.

Before the quantification of activity distribution the ACS software performs the attenuation correction through Chang's method first order. The present paper describes the development of the ACS software and its validation.

2. MATERIAL AND METHODS

2.1. Chang's attenuation correction method

In general, this method corrects the attenuation process multiplying the SPECT images by a correction matrix, denominated C(x, y) [9]. This matrix is defined by:

$$C(x,y) = \frac{1}{\frac{1}{M}\sum_{i=1}^{M} e^{-\mu \cdot L(x,y,\theta_i)}} \quad (1)$$

where:

- M is the number of projection;
- μ is the linear attenuation correction of the medium;
- $L(x,y,\theta_i)$ is the length from the point (x, y) to the edge of the attenuator medium in the angle θ_i.

2.2. Formulation of the algorithm of Chang's attenuation correction method implemented in the ACS (Attenuation Correction SPECT) software.

Before starting the process of formation of the correction matrix, one must delimit the region of interest (ROI) in the SPECT image. This region is normally circular and represents the contour of the patient's body in this section. After this process, a matrix of same dimension as the SPECT image is formed where the matrix elements outside the ROI will receive a value equal to zero and those inside will receive a value different from zero. Thus, the process of construction of the correction matrix basically occurs in three iterative steps:

1. In the first step the position of a nonzero element in new matrix is found;
2. In the second step the calculation of C(x, y) by Equation 1is initialized;

3. In the third step the value of C(x, y) calculated is assigned to its correspondent position, then the algorithm returns to the first step as the starting point. This process is carried on until the end of the matrix.

2.2.1. Procedure for calculating the correction matrix C(x, y)

Below it is described, step by step, the procedure followed to construct the C(x, y) matrix:

1. The angle (θ_i) of the first projection is obtained ;
2. Based on this angle the calculation of L(x, y, θ_i) which is the length from the point (x, y) to the edge of the attenuator medium is performed;
3. This value is then multiplied by the pixel size given in centimeters;
4. The result is then multiplied by -1 and by the attenuation coefficient (μ) of the medium;
5. Calculate the exponential of the previous result;
6. This result is stored in a vector;
7. Set up another angle θ_i;
8. The procedure from the first step up to the seventh step is repeated for all projections (θ_i);
9. Add up all the values of the vector constructed in the sixth step.
10. The result is then divided by the number of projections;
11. Finally, the inverse of this result is calculated to obtain the C(x, y).

Figure 1 shows the parameters layout.

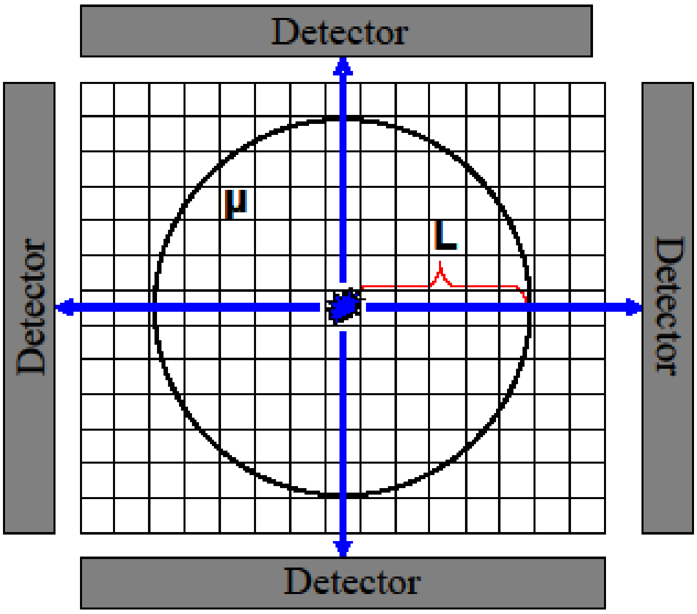

Figure 1. Parameters layout used in the construction of C(x,y) matrix.

2.3 ACS software (Attenuation Correction SPECT)

ACS software has been developed as a ImageJ software [10] plugin, so that, it is initialized opening a SPECT image through ImageJ and to perform the ROI. This specifies the region that will be processed. Figure 2 shows the initial window of the ACS software.

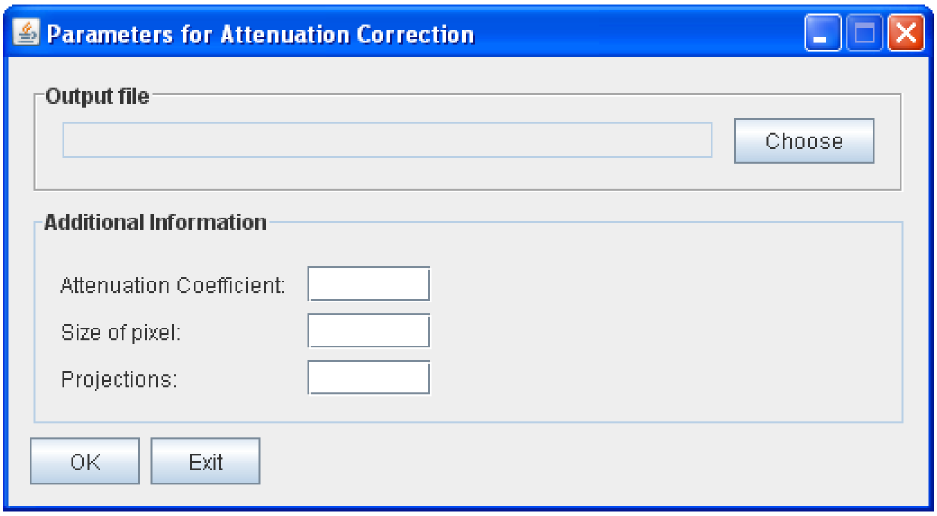

Figure 2. Initial window of the ACS software.

Basically, this software is composed by three modules. Together, they are intended to provide quantitative data corresponding to the relative activity obtained from a SPECT image and to store this information on an ASCII format file.

2.4. Procedure to evaluate the Chang's method implemented in the ACS

2.4.1. Verification of C(x,y) matrix

To verify the construction of matrix C(x,y) by ACS, it was used a 5 X 5 matrix filled with 0 and 1, as shown in Figure 3.

0	**0**	**0**	**0**	**0**
0	**0**	**1**	**0**	**0**
0	**1**	**1**	**1**	**0**
0	**0**	**1**	**0**	**0**
0	**0**	**0**	**0**	**0**

Figure 3. Matrix used to check the ACS software.

The construction of C(x, y) matrix by ACS was verified by comparing it to the manually obtained results through equation 1.

The values of the attenuation coefficient, pixel size and projections number used in this verification were 0.15 cm^{-1}, 1 cm and 4, respectively.

2.4.2. Analysis of the attenuation correction in a SPECT image

Once the correction matrix is verified it was applied to the attenuation correction in a simulated 64 X 64 and 128 projections SPECT images. The image was simulated by SIMIND [11] software as a water cylinder filled with Tc^{99m} homogeneously distributed in its volume. The pixel size was set to 0.54 cm. Figure 4 shows a cross section of the reconstructed cylinder.

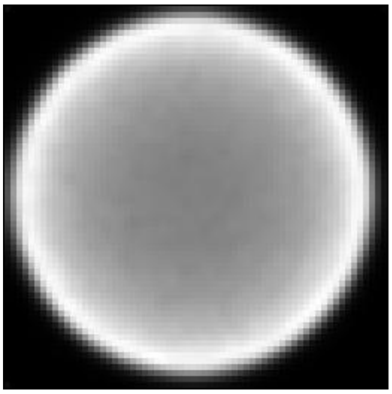

Figure 4. Cross-sectional view of the simulated SPECT image.

3. RESULTS

3.1. Correction matrix, C(x,y)

Figure 5 shows a layout of the image used in association with the values and indexes of each pixel. There is also the location of the ROI in this image.

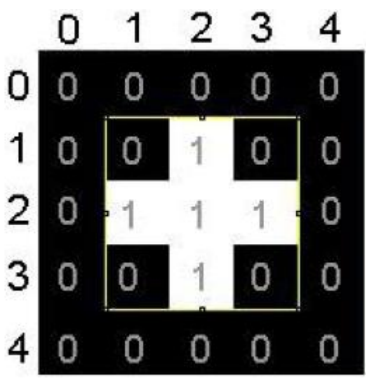

Figure 5. Image used to verify the ACS software.

Attenuation correction, pixel size and projection number were 0.15 cm^{-1}, 1 cm and 4, respectively. Figure 6 presents the C (x,y) matrix constructed by ACS software.

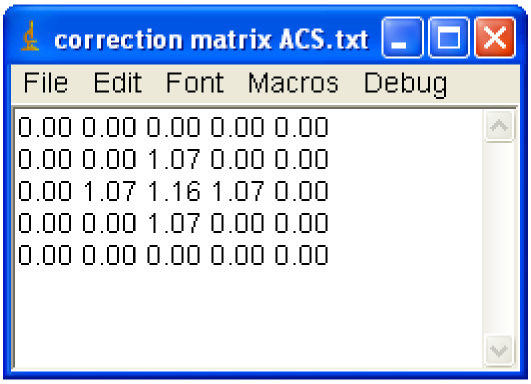

Figure 6. Correction matrix C(x,y) created by ACS software.

The calculation of C (x, y) was performed by Equation 1 as shown below. As an example, equations, (2) and (3) show respectively, the calculations performed to the central element of the image and one of its neighbors, because, in this case, all elements around the center must have the same result.

Calculation of the central element:

$$C(2,2) = \frac{1}{\frac{1}{4} \cdot (4) \cdot e^{-0.15 \cdot 1}} = 1.16 \tag{2}$$

Calculation of the adjacent element to central:

$$C(1,2) = \frac{1}{\frac{1}{4} \cdot \left[3 \cdot e^{-0.15 \cdot (0)} + 1 \cdot e^{-0.15 \cdot (2)}\right]} = 1.07 \tag{3}$$

Based on these results it verified if the ACS software to implement correctly the construction of the correction matrix C(x, y).

3.2. Analysis of the attenuation correction using a SPECT image

Figure 7 shows the central axial profile of the image before performing the attenuation correction by ACS software. The axial profile which would be expected in this region is a plateau, which is not observed due to photons attenuation.

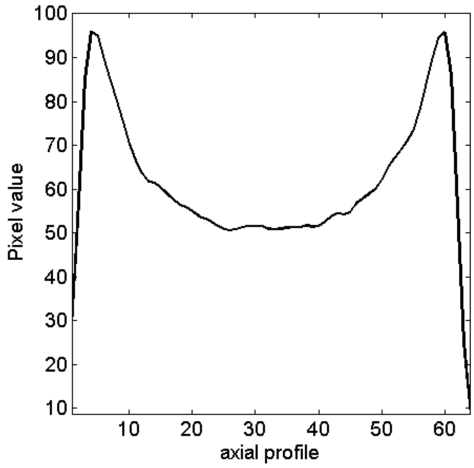

Figure 7. Central axial profile of the uncorrected cylinder.

The result generated by the ACS software together with the central axial profile of the corrected image is shown in Figure 8.

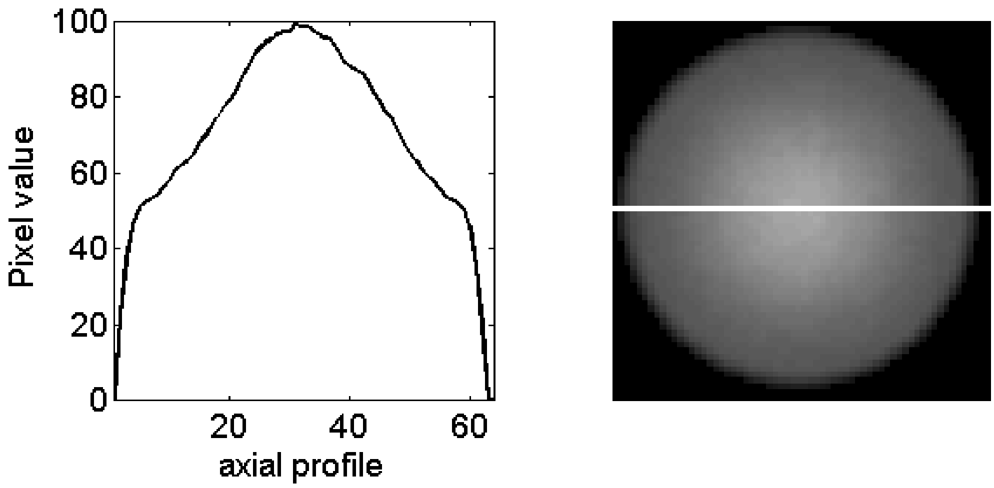

Figure 8. a) Central axial profile of the corrected image and b) Corrected image by ACS software.

When the correction matrix is applied in an extended source, certain areas will be over-corrected and others under-corrected depending on the source distribution [9]. This is clearly shown in Figure 8 where there are regions that were over-corrected, in the center of the circle, and others that were under-corrected, in the edge of the circle.

Therefore, in most cases it is necessary to do a second correction process to compensate those under and over correction [9]. For this correction it is necessary to perform an iterative process with the original image sinogram and is under development.

4. CONCLUSIONS

The ACS software was designed to provide the relative activity distribution by a SPECT image. For this, it was needed to implement a method of attenuation correction. The method chosen was the Chang's attenuation correction method. The aim of this study was to assess whether this method was implemented correctly in the ACS software.

After analyzing the results it was found that the Chang's method was implemented correctly. It was also observed that this method leads to over-correction in some areas of the image and in other under-correction. According to Chang, when accuracy is essential the second correction is needed [9] which is being implemented.

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