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INTERPOLATION STUDIES OF A 3D DOSIMETRIC SYSTEM FOR QUALITY ASSURANCE IN RADIATION THERAPY

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ABSTRACT

With the evolution of radiation therapy techniques, treatments have become increasingly accurate. To ensure a good quality assurance program for modern equipment, Sun Nuclear Corporation has developed ArcCHECK, a 3D dosimetric system, which contains 1386 helically arranged diodes within a PMMA cylindrical structure. The outputs of this system show, in addition to dose values acquired directly from the diodes, also matrices with interpolated dose values, in order to provide values at more than 5000 points for quality assurance. The main purpose of this work is to analyze the interpolated dose values provided by ArcCHECK. For this, simple measurements were taken with ArcCHECK, with a 10x10 cm^2 static field of 6 MeV photons and 100 MU. A algorithm for MATLAB software was also developed so that it was possible to interpolate crude dose values obtained from the diodes and compare them with the values interpolated by the dosimetric system software. Significant dose differences values were found in the relative dose difference between the matrices interpolated by the algorithm and by ArcCHECK. The method used by this dosimetric system presented a diode selection pattern for the interpolation and different when compared to the developed method, even if both were calculated in the 2D plane, based on the dose map acquired by ArcCHECK.

1. INTRODUCTION

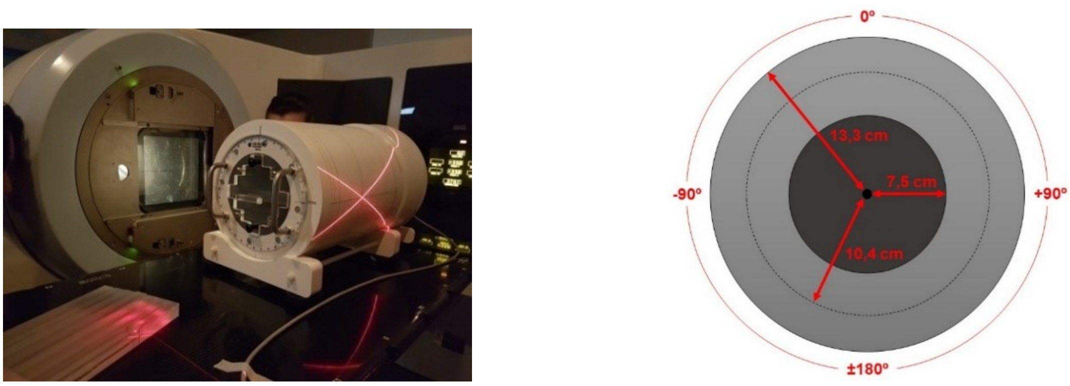
Radiation therapy (RT) is an important phase in cancer treatment and used for most patients with this disease. With the evolution of RT techniques, treatments have become increasingly accurate, which one of the most complex techniques is Volumetric Modulated Arc Therapy (VMAT). In VMAT, three parameters are simultaneously changed during treatment: radiation beam conformation - defined by Multi-leaf Collimator (MLC) -, the delivered dose rate and the rotation speed of the linear accelerator (LINAC) gantry. Thus, the gantry moves continuously while the MLC and dose rate vary in the arc during treatment [1,2,3].

With the improvement of the treatment techniques, radiation therapy quality assurance (QA) techniques and equipment should concomitantly improve in order to ensure accurate measurements and consequently the proper functioning of the dose delivery system. Recently, Sun Nuclear Corporation has developed a 3D dosimetric system composed of 1386 diodes, called ArcCHECK, with the main objective of performing QA of modern LINACs, such as those capable of performing VMAT. In clinical practice, ArcCHECK can be used for both QA of the delivery system and patient-specific QA measures, executed before treatment occurs. Thus, the scope of this work is to develop an algorithm to evaluate the influence of different dose interpolation methods on the dataset acquired by ArcCHECK at Beneficência Portuguesa (BP) hospital [3,4,5].

2. MATERIALS AND METHODS

2.1. ArcCHECK

ArcCHECK is a 3D dosimetric system capable of taking measurements in clinical equipment that involve techniques such as VMAT and Tomotherapy. It is composed of a cylindrical structure of Polymethyl methacrylate (PMMA), equivalent to water, with an external radius of 13.3 cm and a height of 44.29 cm considering the electronic part. As shown in Figure 1-a and b, the system has a cavity with a radius of 7.5 cm, where a plug can be inserted into it. The volume to be inserted include a dosimetric film core, ionization chambers, a diode array, a homogeneous solid core, or a heterogeneous core, with absorption characteristics that may be similar to different tissues [3,6].



(a) **(b)**

Figure 1: (a) Image captured during a day of measurements at BP hospital, while the LINAC gantry was set to radiate ArcCHECK; (b) representation of the radial distances of an axial cut in ArcCHECK and the angles of rotation around it.

In ArcCHECK, radiation detection is performed from a set of 1386 SunPoints diodes helically arranged inside the cylindrical acrylic, at a radius of 10.4 cm, as also shown in Figure 1-b. Each one of the diodes has a sensitive area of 0.64 mm^2 and a volume of 0.019 mm^3, which makes them much smaller than an ionization chamber and, consequently, more sensitive and accurate, especially in cases of patient-specific QA. Fixed in the PMMA, the diodes are spaced 1cm both along the cylindrical length and along circumference, which makes ArcCHECK have 66 diodes each turn in the structure and 21 turns, totaling the 1386 diodes [6,7].

After a measurement, in order to be able to view the values acquired in a 2D plane, the helical detection region, taken as a cylindrical shell, can be opened in a rectangular map, as shown in Figure 2. The x-axis corresponds to the 66 diodes present at each revolution in the cylinder at an angle θ and the y-axis to the 21 turns of the diodes in the system in a length z. Then, corrections to the data are performed by the ArcCHECK software and output files containing various information are generated [6].

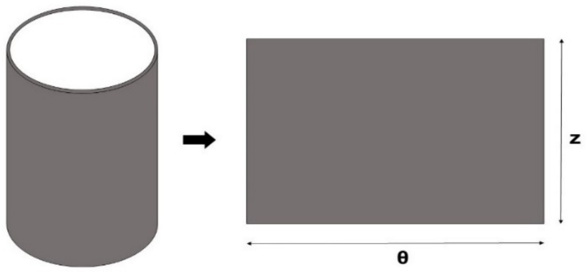


Figure 2: Illustration of the opening of a cylindrical shell on a 2D rectangular map.

The matrices generated containing the interpolated dose values have a size of 41x131 elements, that is approximately four times the size of those matrices containing only the crude dose values of 21x66 elements, in order to provide values at more than 5000 points [6]. In this work, simple measurements were taken using ArcCHECK, in a 10x10 cm^2 photon static field, with a defined dose of 100 MU and nominal energy of 6 MeV. Thus, the output files were used for interpolation analysis.

2.2. Monte Carlo Simulation

Monte Carlo Method (MCM) is a mathematical technique widely used to represent problems that usually involve stochastic processes, such as the interaction of radiation with matter. It uses Probability Density Functions (PDFs), which describe the physical process of the problem of interest. Monte Carlo N-Particle Transport Code (MCNP) is a worldwide Monte Carlo-based code used in several types of radiation transport research involving neutrons, photons, electrons and protons [8,9].

In this work, ArcCHECK was modeled by the description of its physical and composition characteristics. In the location of the diodes, inside the PMMA, a cylindrical shell-shaped mesh was defined, divided into 21x66, that is, 1386 thin meshes of equal size to represent the diodes, as shown in Figure 3. The model was used for MCNP simulation and dose values were obtained by the mesh volumes [6,9,10]. The same model was simulated again, now with the mesh divided into 41x131 (or 5371) thin meshes, similar to the matrix size of ArcCHECK interpolated data.

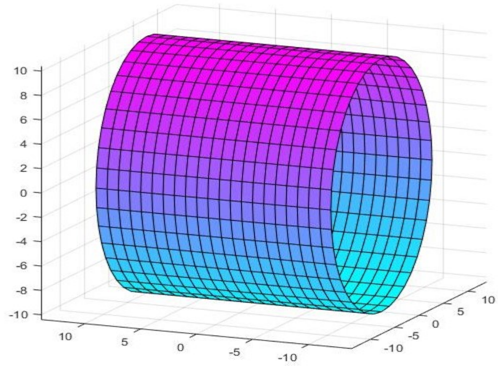


Figure 3: Illustration of a 3D cylindrical shell-shaped mesh.

2.3. Interpolation

Interpolation is a widely used method in several areas, which allows the construction of new data points from already known points. For a set of data representing the values of a function with a limited number of independent variable values, it is possible to estimate the values of that function for intermediate values of the independent variable [11,12].

As previously mentioned, ArcCHECK also provides interpolated data, then an algorithm was developed in MATLAB software [13] in order to evaluate the influence of dose interpolation on the acquired data set. In this algorithm, the initial 2D positions were considered as if a helical configuration had been opened unmodified, where the position at y grows slowly until one turn is completed, as shown in Figure 4. Therefore, the dose values to be interpolated were associated to these positions and the points to be found new values were determined, points in perpendicular positions, in the form of a matrix with 41x131 elements.

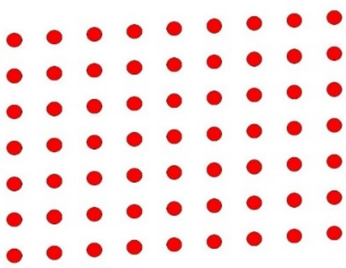


Figure 4: Determined positions for the crude dose values in the algorithm developed for interpolation.

The method used was the inverse distance weighting (IDW) interpolation, where the weight of a given data point is inversely proportional to its distance. Thereby, the four nearest neighbor points of each point to be estimated were identified and the Euclidean distances of these neighbors were used to calculate the dose D_{int}, as shown in Equation 1. N is the number of neighbors, equal to 4, D_i is the dose of the neighbor point i, (x_i, y_i) is the position of this neighbor point i and (x, y) is the position of the point to be interpolated [11,12]. To compare data to assess the impact of interpolation, the relative difference Diff was calculated for each point, as shown in Equation 2, where M_{int} is the interpolated matrix by MATLAB algorithm developed and M_{ref} is the reference matrix.

$$D_{int} = \begin{cases} \dfrac{\sum_{i=1}^{N} \frac{D_i}{\left[(x_i-x)^2 + (y_i-y)^2\right]}}{\sum_{i=1}^{N} \frac{1}{\left[(x_i-x)^2 + (y_i-y)^2\right]}} \text{, } if\ x_i \neq x\ or\ y_i \neq y \\ D_i \text{, } if\ x_i = x\ and\ y_i = y \end{cases} \tag{1}$$

$$Diff = \left[\left(\frac{M_{int}}{M_{ref}}\right) - 1\right] * 100 \tag{2}$$

3. RESULTS AND DISCUSSION

3.1. Algorithm Validation

Both matrices resulting from the simulation with 21x66 volumes and the simulation with 41x131 volumes were normalized to the maximum value of each one and the doses below 10% of the maximum dose were equal to zero. Then, the data acquired by the simulation with 21x66 volumes were interpolated using the algorithm developed for MATLAB and the relative dose difference was calculated among the matrices, in which the matrix resulting from the simulation with 41x131 volumes was the reference in the denominator of the calculation.

This was done so that the interpolation algorithm could be validated. The differences found were very small, as expected from a comparison between two rectangular matrices, except for a few points exactly at the edges of the field in ArcCHECK, which showed maximum differences of 81% and minimum of -45%. These points are in the penumbra region, where the dose goes from 80 to 20% in a small distance, and the smoothing caused by the interpolation does not reproduce this reality for these points. Then, the algorithm for data interpolation in MATLAB was considered validated.

3.2. Application to ArcCHECK Data

The same comparison was made between the crude dose matrix obtained with ArcCHECK measurements, and interpolated using the algorithm for MATLAB, and the matrix interpolated by ArcCHECK software. As shown in Figure 5, the maximum discrepancy found was 110% and the minimum was -100%, represented by one or two points darker and bluer. However, the most persistent differences are those around ±30%, more visible at the upper and lower edges of the field exit. It is mainly due to the fact that the crude data positioned as in Figure 4 and interpolated to the rectangular positions were compared to the data rearranged by the ArcCHECK software without any correction for the dose values, causing a shear.

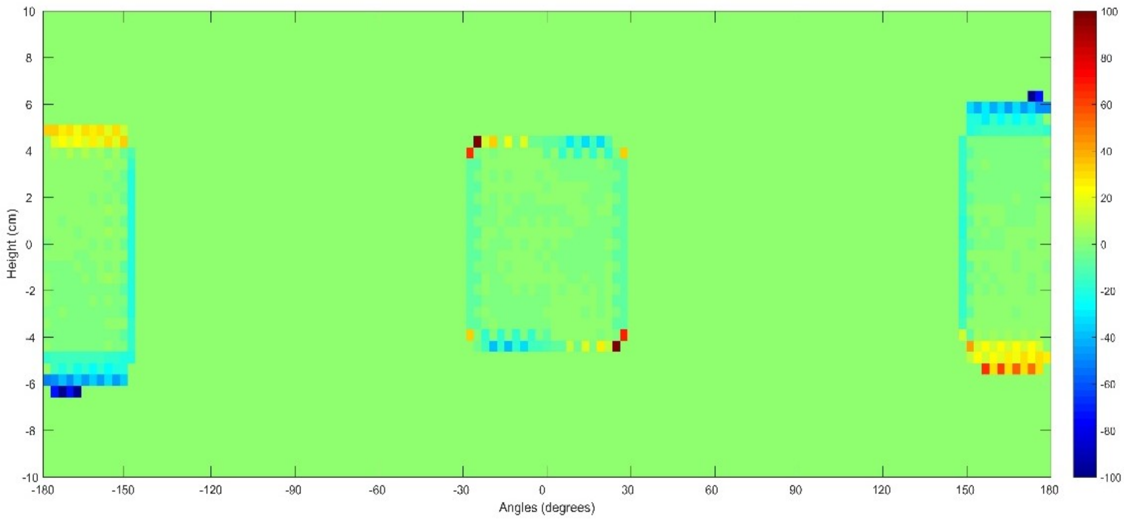


Figure 5: Map of the relative dose difference between the crude experimental data interpolated in MATLAB and the experimental data interpolated by the ArcCHECK software, both normalized.

A detail that is not visible in the above image is shown in Figure 6, when adjusting the color scale, where limits of ±0.1% have been defined and any difference value below or above has the same color as the lower or the higher limit. In it, zero value points alternate with points of small differences in both the first and last column of the map, at the field exit region. This effect is not observed when calculating the difference between the matrices simulated with the rectangular mesh. It is due to the interpolation method used by the ArcCHECK software, which does not estimate dose values at all of the edges of the map, probably because it does not find exactly four neighbors close to the calculation but only three.

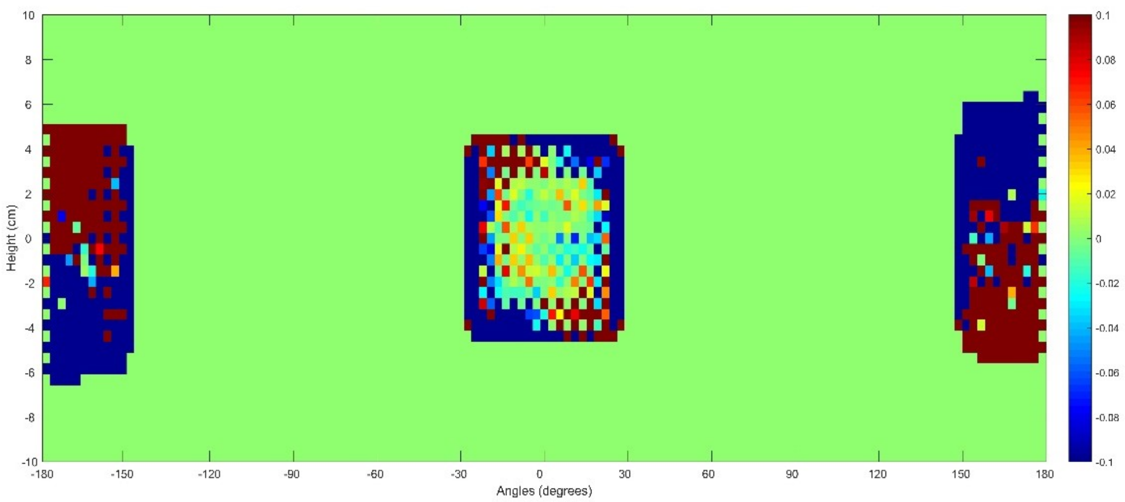
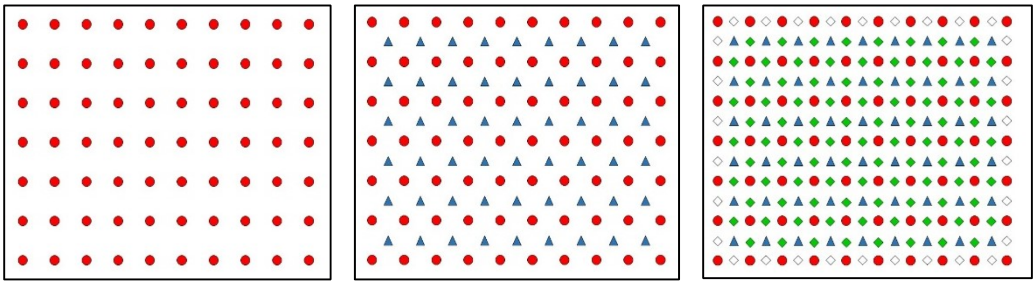


Figure 6: Map of the relative dose difference between the crude experimental data interpolated in MATLAB and the experimental data interpolated by the ArcCHECK software, both normalized, with scale readjustment.

In Figure 7, it is possible to follow the steps with which ArcCHECK performs this interpolation, where the number of elements in the figures does not represent the actual quantity of elements in the arrays. First, through the crude dose values acquired directly from the diodes, represented by the red circles in (a), the software uses four diodes closer to find dose values in the middle of these four. These values are linearly interpolated and represented by the blue triangles in (b). Then, the red and blue points are used to interpolate values between them, resulting in the values represented by the green lozenges in (c). The empty lozenges, at the corners of the map, represent the zeros already mentioned, that is, points for which the software does not calculate dose values.



(a) (b) (c)

Figure 7: Illustration of the interpolation methodology of ArcCHECK software; (a) red circles represent the diodes; (b) blue triangles represent the first interpolated points; (c) green lozenges represent the second interpolated points.

4. CONCLUSIONS

The algorithm developed for data interpolation in MATLAB allowed to investigate the effects of diode data interpolation performed by ArcCHECK software, that is, to visualize the dentate pattern of zero doses at the edges of the dose distributions. The user of this system can, when generating the dose maps, select the display of the crude dose in the interface, so this effect does not interfere with data visualization.

Also, any interpolation method chosen will not be fully representative in the high dose gradient regions. In future work, it will be possible to change this method by applying certain restrictions for low dose values or large falls of these values, for further investigation of the interpolation method used by ArcCHECK.

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