Automatic 2D Scintillation Camera and Computed Tomography Whole-body Image Registration to perform Dosimetry Calculation.

Federico Cismondi, Sergio L. Mosconi
Fundación Escuela de Medicina Nuclear, Mendoza, Argentina.
fcismondi@hotmail.com

Abstract. In this paper we present a software tool that has been developed to allow automatic registrations of 2D Scintillation Camera (SC) and Computed Tomography (CT) images. This tool, used with a dosimetric software with Integrated Activity or Residence Time as input data, allows the user to assess physicians about effects of radiodiagnostic or radioterapeutic practices. Images are registered locally and globally, maximizing Mutual Information coefficient between regions been registered. In the regional case whole-body images are segmented into five regions: head, thorax, pelvis, left and right legs. Each region has its own registration parameters, which are optimized through Powell-Brent minimization method that “maximizes” Mutual Information coefficient. This software tool allows the user to draw ROIs, input isotope characteristics and finally calculate Integrated Activity or Residence Time in one or many specific organ. These last values can be introduced in many dosimetric softwares to finally obtain Absorbed Dose values. Keywords—2D Images, Internal Dosimetry, Automatic Registration.

1. Introduction.
Crescent uses of open radioactive sources in therapeutic practices has moved physicists and engineers that work in Nuclear Medicine to develop tools that helps them in assessing physicians about dosimetric effects off those practices. These tools help in quantifying the real effect of radiations at tissular level and in modifying therapies following those effects [2,3,5].

Besides, introduction of new radio-pharmaceutics in the clinical practice requires methods that allow testing accurately their metabolism inside human body. In this way, knowing intaken activities in each organ under research and the dosimetric limits of these organs, physicians can recognize in a certain way dangerous effects of the method as well as its feasibility for clinical use.

There are many ways to achieve these goals [3,6,12,15]. In our work the imagenologic alternative was used to perform dosimetric calculations, using 2D whole-body images of patients injected with open radioactive sources [7,8,11,13,14]. To obtain accurate results it’s necessary to process images and correct them using Scattering and Attenuation considerations as well as patient movements during the acquisition, differences in patient positioning before the acquisition starts, etc. [3,6,7,8,11,13,14].
A software to perform automatic 2D whole-body image registration has been developed, which can be used with scintillation camera and axial computed tomography (scout) images. The registration procedure allows images acquired in a temporal sequence to be “superposed”, making easier the activity calculus over anatomical regions predefined in images. This activity values are then processed to obtain Integrated Activity and Residence Time values on those regions, which can be finally used to calculate Absorbed Dose.

2. Software Design.

2.1. Materials.
Software has been developed in a Xeleris platform of General Electric. Software developing language was Aladdin, an object-oriented Visual Basic script [1]. Nuclear Medicine images were obtained with a dual-head Helix Elscint scintillation camera and CT images were obtained with a Hi-Speed General Electric scanner.

Obtained images are 2D whole-body images of patients injected with Samarium153, used as a palliative therapy against active bone metastases lesions pain [5].

2.2. Mutual Information measurement as a registration method.
Registration was performed maximizing Mutual Information Coefficient (MI) explained through Information Theory, a component of Probabilities Theory, which relates occurrence probabilities of a specific variable with the uncertainty that one have about it [4,9,10,14,17]. Entropy of a random variable measures the uncertainty degree of it.

\[
H(A) = - \sum_a p_a(a) \log p_a(a)
\]  

(1)

With \( p_a \) as the probability off A. Besides, Joint Entropy measures the remaining uncertainty degree in a variable A after knowing another random variable B.

\[
H(A|B) = - \sum_a \sum_b p_{ab}(a,b) \log p_{ab}(a|b)
\]  

(2)

MI measures the dependence degree between to random variables A and B.

\[
MI(A,B) = H(A) + H(B) - H(A,B)
\]  

(3)

\[
MI(A,B) = H(A) - H(A|B)
\]  

(4)

\[
MI(A,B) = H(B) - H(B|A)
\]  

(5)

Used in images, Mutual Information give us an idea of how good aligned are two images, treating these images as two groups of random discrete variables. “Maximizing Mutual Information between two random variables you find the major complexity possible between two separated groups of data (images) (maximizing the first two terms of (3)), in such a way that at the same time they explain each other as good as possible (minimizing the last term of (3))”[17]. MI reaches its maximum when two images are correctly aligned, while its value diminishes as the images are misaligned.
Normalized Marginal and Joint histograms can be used as probability estimators of random variable’s values of images (grey levels). All needed information to register two images is contained inside themselves and there’s no need to input additional information provided by the user [14,17].

A correct repositioning can be obtained maximizing MI coefficient, so images can be used for quantification procedures. The maximization algorithm used was Powell-Brent directions-set method, specially adapted for the Aladdin script [10,18]. This method looks for a global minimum of a given function (in our case, the inverse of the function, because we need to find the maximum) in different directions over the registration parameters space, refreshing and changing these directions with the results obtained in each search cycle.

3. Development.
Our software consist of four principal sections:
- Image preparation.
- Coarse registration.
- Accurate registration.
- Residence Time calculation.

During image preparation, the software verifies the existence of emission and transmission images needed to perform different corrections. Two series of anterior-posterior emission images acquired at different times after the injection of the radioactive material are strictly necessary [11,13]. With those images, the software can only perform Residence Time calculations with an important error because those emission images have not suffered a scattering and attenuation correction procedure.

If there are more emission images, as well as scattering or transmission images the software performs corrections on both anterior and posterior emission images, which after this procedure are ready to be registered.

Coarse registration repositionate images using the result obtained after the cross-correlation between two images [17]. The first Product Image in the temporal sequence is selected in our software as the stationary one.

Cross-correlation between two 2D data series of sizes NxM and PxQ results in a 2D series with the dimensions (M+P+1)x(N+Q+1). In 1D can be seen that:

If you try to represent results in series shorter than those recommended by this last “rule”, aliasing between periodic result series appears and data series are distorted. Graphically and in 1D it can be seen that:
However, with most nuclear medicine whole-body images a sharp maximum appears in the spatial position in which both images are well superposed. This maximum decays very fast for small misalignments between images. So:

For this last 1D series it can be seen that maximums remain at the same position and easy to recognize, and the aliasing does not affect the cross-correlation procedure. In this way, images can be registered using a resultant “image” (the cross-correlation image) with the same size of the input ones (Figure 1 (b)).

This is an innovation in image correlation field that has been not been researched in other works. However, the real importance of this discovery was that Aladdin software doesn’t allow working with images bigger than 1024x1024 pixels [1]. Whole-body images have sizes of 1024x256 pixels (Figure 1 (a)), so cross-correlation between them results in data series of 2048x512 pixels. It can be seen that it’s not possible to process this result unless you divide the results in two arrays of 1024x512 pixels, but this is very complex.

Once the coarse registration procedure ends, the user can perform an accurate registration, which divides images in five regions (Figure 2):

- Head.
- Thorax and abdomen.
- Pelvis.
- Right leg.
- Left leg.

This region segmentation is arbitrary applied using a standard rule adopted from other works defined by experienced physicians [14].
Each region suffers different geometric transformations that try to correctly repositionate them locally. All image information is used to perform some repositioning. Using Powell-Brent method the MI coefficient is maximized in each region, finally finding the set of parameters that correctly register this region [18]. Parameters are then applied over the floating image in a specific sequence that allows improvements in repositioning without “ruinning” previously obtained improvements.

Figure 2. Lines that define five regions can be observed. Each region is the registered independently (local) and globally.

Images are repositioned until they reach a prefixed accurateness (tolerance) arbitrary used during programming. When this process ends, resulting images are showed (Figures 3 and 4) so user can visually control how well the images were registered, deciding to repeat the process if it was needed.

Figure 3. Non-registered images, in which can be seen different ROIs simultaneously drawn. Please compare instantaneous activity values for each ROI of Figure 4.
Figure 4. Resulting images after a registration procedure, where can be seen ROIs simultaneously drawn. Instantaneous activity values of each ROI are used to obtain Integrated Activity and Residence Times values. It can be seen that ROIs are in the same anatomical localization in both images.

Correctly registered images can be use then to perform Residence Time and Integrated Activity calculations [11,13]. This software allows the user to define ROIs over registered images, using shaped-ROIs (rectangle, circle, ellipse, etc.) or irregular ROIs.

The software obtains then the number of events (counts) per pixel in each pixel of a specific ROI. Knowing the calibration constant of the scintillation camera used to acquire nuclear medicine images, the instantaneous activity value can be obtained for each pixel. With these instantaneous activity values one can perform an integration calculus to obtain the Integrated Activity value [13].

There are several methods to integrate a data set, but MIRD Pamphlet 16 recommends the use of a fitting sum of exponentials that fits the effective decay function. This sum of exponentials can be easily integrated [11,13,17]. In this software fitting was performed using Minimum Squares and the user can define the number of exponentials in the sum.

Finally, a text format file is generated with those values obtained for each ROI. This file can be used as input in many dosimetric softwares like LundADose, MIRDose, OLINDA, etc., that allows us to obtain Absorbed Dose values for each ROI.

4. Results.
This software has been used with patients treated with a palliative therapy against bone metastases pain using Sm 153. Results have not been compared with other registration and dosimetry calculation methods. It’s important to remember that 2D images have intrinsic errors that cannot be solved with this method (patient’s movements out of the acquisition plane) that makes it useful only under certain circumstances. However, several big movements in the acquisition plane can be repositioned improving significantly the dosimetric accuracy.
5. Conclusions.
There are no commercial softwares that perform a correct registration of 2D images like the one developed in this work. Tools that really need this image preprocessing must attach other tools that perform it. Our software has been developed to be used with medical images, but with very few modifications it can be used to repositionate any type of images. This feature is enforced by the use of Mutual Information concept and Powell-Brent method. Besides, these last components become the software totally independent from the user.

In dosimetric calculations several discrepancies can be found because 2D dosimetry assumes and applies a lot off corrections that can be sometimes not so real and needed. However, results obtained with this software allow us to prognosticate dose effects due to radioactive injections with considerable accurateness.

Particularly with Sm 153, dosimetry performed over images post-injection is not very useful, but in therapies that involves radioactive isotopes like Indium and Yttrium dosimetry has a singular importance and is because of this that it’s really necessary to have tools that allow planning of these therapies.

References
[1] Aladdin TM. Aladdin User Manual. General Electric.
[2] Cabrejas Raúl C., Levi de Cabrejas Mariana. "Instrumentación. Parámetros característicos". Tomografía en Medicina Nuclear. 1ª edición, Año 1999.
[3] Carpintiero Silvina M.. "Cuantificación de las Imágenes de SPECT". Tomografía en Medicina Nuclear. 1ª edición, Año 1999.
[4] Chen Hua-mei, Arora Manoj K. and Varshney Pramod K. “Mutual Information based Image Registration for remote sensing data”.
[5] "Guidelines for Radionuclide Therapy of Refractory Metastatic Bone Pain". Belgisch Genootschap voor Nucleaire Geneeskunde. Sociedad Belga de Medicina Nuclear.
[6] John L. Humm, Roger W. Howell, Dandamudi V. Rao. “AAPM Report No. 49, Dosimetry of Auger-Electron-Emitting Radionuclides”. Medical Physics, Vol. 21, Issue 12, December 1994.
[7] Ljungberg Michael. "Principles of the gamma camera, the underlying problem with scatter and activity calculations from planar images". Curso de Dosimetria Interna en Medicina Nuclear. Buenos Aires, Argentina 2004.
[8] Ljungberg Michael. "Scatter and attenuation correction in SPECT". Curso de Dosimetria Interna en Medicina Nuclear. Buenos Aires, Argentina 2004.
[9] Maes Frederik. “Chapter 4: Multimodality Image registration by Maximization of Mutual Information: Theory and Implementation”. PhD Thesis.
[10] Maes Frederik, Collignon André, Vendermeulen Dirk, Marchal Guy and Suetens Paul. “Multimodality Image Registration by Maximization of Mutual Information”. IEEE, 1996.
[11] Rojo Ana María, Gómez Parada Inés. “Metodología MIRD”. Curso de Dosimetría Interna en Medicina Nuclear. Buenos Aires, Argentina 2004.
[12] Sgouros George. “Dosimetry of Internal Emitters”. The Journal of Nuclear Medicine. Vol. 46. N° 1. 2005.
[13] Siegel Jeffry A., Thomas Stephen R., Stubbs James B., Stabin Michael G., Hays Marguerite T., Koral Keneth F., Robertson James S., Howell Roger W., Wessels Barry W., Fischer Darrel R., Weber David A. and Brill Bertrand. “MIRD Pamphlet N° 16: Techniques for Quantitative Radiopharmaceutical Biodistribution Data Acquisition and Analysis for Use in Human Radiation Dose Estimates”. MIRD Pamphlet N° 16. Journal of Nuclear Medicine, 1999.
[14] Sjögreen Katarina, Ljungberg Michael, Wingårdh Karin, Erlandsson Kjell and Strand Sven-
Erik. “Registration of Emission and Transmission Whole-Body Scintillation-Camera Images”. *Journal of Nuclear Medicine*, 2001.

[15] Stabin Michael G. "Radiation Dose Assessment in Nuclear Medicine". *Curso de Dosimetría Interna en Medicina Nuclear*. Buenos Aires, Argentina 2004.

[16] The Scientist and Engineer’s Guide to Digital Signal Processing. “Capítulo 12: The Fast Fourier Transform”.

[17] Viola Paul, Wells William M. “Alignment by Maximization of Mutual Information”. *A. I. Technical Report*, 1995.

[18] Xu Xiaoyan, Dony Robert D. Differential evolution with Powell’s direction set method in Medical Image Registration”. School of Engineering, University of Guelph, Guelph, ON, Canada. IEEE 2004.