PhD Thesis:

Development of stopping rule methods for the MLEM and OSEM algorithms used in PET image reconstruction

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ABSTRACT

The aim of this Thesis is the development of stopping rules for the maximum likelihood expectation maximization (MLEM) and ordered subsets expectation maximization (OSEM) iterative algorithms, used in positron emission tomography (PET) image reconstruction. The iterative algorithms introduce noise after a number of iterations and the problem can be manipulated with two methods; a) regularization and b) stopping rules. Regularization is the use of some functions in such way so that the reconstructed image is a compromise between the data and the object. Stopping rules aim to stop the algorithm at the iteration where the maximum likelihood of the reconstructed image is reached. Development of the stopping rules is based on the study of the properties of the MLEM and OSEM algorithms. By analyzing the mathematical expression of both algorithms, it can be observed that the pixel updating coefficients play a key role in the upgrading process of the reconstructed image from iteration *k* to *k+1*. For the analysis of the properties of these algorithms, a PET scanner geometry was simulated using Monte Carlo methods.

For image reconstruction using iterative techniques, the calculation of the transition matrix is essential. The transition matrix fully depends on the geometrical characteristics of the PET scanner. For its calculation, a methodology has been developed based on a Monte Carlo approach, which is preferred in comparison to analytical methods due to its lower complexity. To this direction two sets of digital phantoms were used: the 4D digital mouse whole body (MOBY) and the digital Hoffman brain phantoms. For each one of these phantoms, simulated noise-free data sets have been generated at different activity distribution levels. In addition,

the Digimouse phantom was used for the validation of the methodologies developed. The MLEM and OSEM algorithms were used to reconstruct the projection data generated from these phantoms. In order to compare the reconstructed and true images, specific figures of merit (FOM) were used.

Firstly, an analysis of the updating coefficients behavior of the MLEM algorithm was performed. The behavior of the pixel updating coefficients values C, for a zero and non-zero pixel in the phantom image was analyzed. Further analyses were performed to find out the dependence of C_{min} (the minimum of the C values that correspond to the non-zero pixels of the reconstructed image) on the image characteristics, image topology and activity level. The analysis showed that the proper parameterization of C_{min} allows the establishment of a robust stopping rule for the MLEM algorithm. The proposed stopping rule was developed based on the evaluation of the reconstructed image quality using the FOMs employed.

Furthermore, following a different approach, a new stopping rule using the log-likelihood properties of the MLEM algorithm has been developed. The two rules were evaluated using the Digimouse phantom. The study revealed that both stopping rules produce reconstructed images with similar properties.

On the other hand, the OSEM algorithm represents an accelerated version of the MLEM algorithm with the main difference that the projection data are grouped into subsets. The role of the selection of the number of subsets in the OSEM algorithm was further studied and it was found that it affects the behavior of C_{min} values. The main assumption is that it is impossible to predict the behavior of the updating coefficients of the OSEM algorithm knowing only the behavior of the updating coefficient of the MLEM algorithm (OSEM with one subset). Hence, a stopping rule for the OSEM algorithm dedicated to each number of subset is essential. In the last part of the Thesis a stopping rule for the OSEM algorithm has been proposed.

Our study shows that the development of stopping rule methods for the iterative reconstruction algorithms used in modern PET scanner is possible. The proposed stopping rules can be developed for any PET scanner. They are independent of the image size and topology but they strongly depend on the detected counts. Therefore, the use of these stopping rules in the image reconstruction of real PET studies is possible.