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Improved Simultaneous Algebraic Reconstruction Technique Algorithm for Positron-Emission Tomography Image Reconstruction via Minimizing the Fast Total Variation

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ABSTRACT

Context: There has been considerable progress in the instrumentation for data measurement and computer methods for generating images of measured PET data. These computer methods have been developed to solve the inverse problem, also known as the "image reconstruction from projections" problem.

Aim: In this paper, we propose a modified Simultaneous Algebraic Reconstruction Technique (SART) algorithm to improve the quality of image reconstruction by incorporating total variation (TV) minimization into the iterative SART algorithm.

Methodology: The SART updates the estimated image by forward projecting the initial image onto the sinogram space. Then, the difference between the estimated sinogram and the given sinogram is back-projected onto the image domain. This difference is then subtracted from the initial image to obtain a corrected image. Fast total variation (FTV) minimization is applied to the image obtained in the SART step. The second step is the result obtained from the previous FTV update. The SART and the FTV minimization steps run iteratively in an alternating manner. Fifty iterations were applied to the SART algorithm used in each of the regularization-based methods. In addition to the conventional SART algorithm, spatial smoothing was used to enhance the quality of the image. All images were sized at 128 × 128 pixels.

Results: ResultsThe proposed algorithm successfully accomplished edge preservation. A detailed scrutiny revealed that the reconstruction algorithms differed; for example, the SART and the proposed FTV-SART algorithm effectively preserved the hot lesion edges, whereas artifacts and deviations were more likely to occur in the ART algorithm than in the other algorithms.

Conclusions: Compared to the standard SART, the proposed algorithm is more robust in removing background noise while preserving edges to suppress the existent image artifacts. The quality measurements and visual inspections show a significant improvement in image quality compared to the conventional SART and Algebraic Reconstruction Technique (ART) algorithms.

RÉSUMÉ

Contexte : Il y a eu des progrès considérables dans l'instrumentation de mesure de données et les méthodes informatiques permettant de générer des images des données de TEP mesurées. Ces méthodes informatiques ont été développées pour résoudre le problème inverse, aussi appelé problème de « reconstruction de l'image à partir des projections ».

But : Dans cet article, les auteurs proposent un algorithme modifié pour la technique de reconstruction algébrique simultanée (SART), de façon à améliorer la qualité de la reconstruction de l'image en incorporant la minimisation de la variation totale (TV) dans l'algorithme itératif de SART.

Méthodologie : L'algorithme SART met à jour l'image estimative en faisant une projection avant de l'image sur l'espace du sinogramme. La différence entre le sinogramme estimé et le sinogramme donné est ensuite rétroprojetée sur le domaine de l'image. Cette différence est ensuite soustraite de l'image initiale pour obtenir une image corrigée. La minimisation rapide de la variation totale (FTV) est appliquée à l'image obtenue dans l'étape SART. La deuxième étape est le résultat obtenu de la mise à jour FTV précédente. Les étapes de SART et de minimisation FTV sont conduites de façon itérative, en alternance. Cinquante itérations ont été appliquées à l'algorithme SART utilisé dans chacune des méthodes fondées sur la régularisation. En plus de l'algorithme SART conventionnel, le lissage spatial a été utilisé pour améliorer la qualité de l'image. Toutes les images ont été produites en format 128 x 128 pixels.

Résultats : L'algorithme proposé a préservé les bordures avec succès. Un examen détaillé révèle que les algorithmes de reconstruction étaient différents; par exemple, l'algorithme SART et l'algorithme SART-FTV proposé ont préservé efficacement les bordures chaudes

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des lésions, tandis que les artefacts et les déviations étaient plus susceptibles d'apparaître dans l'algorithme ART que dans les autres algorithmes.

Conclusion : En comparaison de l'algorithme SART standard l'algorithme proposé réussit mieux à éliminer le bruit ambiant tout en préservant les bordures pour supprimer les artefacts existants. Les mesures de qualité et l'inspection visuelle montrent une amélioration significative de la qualité de l'image comparativement à l'algorithme SART traditionnel et à l'algorithme de technique de reconstruction algébrique (ART).

Keywords: SART algorithm; fast total variation; regularization; PET; image reconstruction

Introduction

The objective of positron-emission tomography (PET) [1, 2] has been devoted to clinical applications. The aim of PET is to provide information about the activities at the cellular level in the body by generating three-dimensional images from projection data by introducing a radioactive tracer into a vein [3]. The tracer consists of a radionuclide that is chemically bound to a biologically active molecule, often a glucose analog. The molecule accumulates in cells that are most metabolically active; if the molecule is specific to the receptor, it gathers in the cells where the receptors are present. This assessment of cellular and physiological function by nuclear medicine can be used to locate and determine the extent of a disease in the body. PET has wide-ranging applications including cardiac [4] and brain [5] imaging, and PET has always been applied to neurology. It has been useful in studying the synthesis and transport of the neurotransmitter dopamine in Parkinson's patients and has also been used to observe tau proteins in Alzheimer's patients [6]. The PET scan is a primary tool for the detection and characterization of cancer and cardiovascular disease [7]. The reconstruction of the isotopic distribution of the concentration is an ill-posed inverse problem. The approaches to solving these problems can be divided into two categories: analytical methods based on the inverse of the Radon transformation and iterative methods based on statistical methods [8–13]. The tomographic data are noisy owing to the random nature of the radioactive decay, and therefore, it is simple to consider the reconstruction of PET as a problem of statistical estimation. During the reconstruction of PET images, these approaches must introduce statistical modeling of data and use previous information about the PET imaging system, which is often referred to as the system probability matrix. For example, the assumptions of Poisson/Gaussian noise on the measurement of photon counting data can be used to treat the measurement uncertainties, thus limiting the solution to the problem of reconstruction space in the frameworks based on the maximum likelihood/least square estimate [14–18]. The reconstruction of an image from noisy PET projection data is difficult because the inverse problem is ill-posed and the reconstructed image is generally very noisy. To enhance the quality of the reconstructed images and obtain an accurate diagnosis, it is desirable to use a spatial regularization that penalizes the difference in intensity of the image between neighboring pixels.

A common way to combine prior information in the reconstruction of the PET image is to use the regularization where the edge is preserved. There are different regularization methods [19–25]. A particularly successful example is the Bowsher method [26]. This method adapts the neighboring pixels for each pixel in the estimation of the image using the information from a previous image in an anatomically informed penalty function better than others, in terms of performance and computational complexity. In addition to regularized reconstruction methods, noise smoothing can be conducted in the image (postreconstruction) [27], in the sinogram domain (prereconstruction) [28–30], or during iterative statistical-based reconstruction process. An alternative method called non-local means [31] incorporates pre-existing knowledge into denoising images. In general, it is easier to denoise images postreconstruction rather than use reconstruction methods based on regularization. This article proposes a modified simultaneous algebraic reconstruction technique (SART) [32] algorithm to improve image quality by incorporating total variation (TV) minimization into the iterative SART algorithm. Noise is modeled in the projection domain, whereas the PET data are effectively modeled by independent Poisson random variables. The results exceeded those of the conventional SART and algebraic reconstruction tomography (ART) reconstruction methods and indicated that the fast total variation (FTV)–SART method provides effective reconstruction and resolution.

The Materials and Methods section of this article outlines the novel SART algorithm based on a regularization method using FTV minimization. The Simulation Studies section presents the PET setup and the evaluation criteria for the quality of reconstruction. Finally, the Performance Evaluation section presents the results, along with a comparison of the proposed algorithm with other methods.

Material and Methods

The organization of the measured PET data generally takes the form of a set of parallel slices that can be independently reconstructed. A PET apparatus collects slices of raw data, each of which is a list of coincidence events denoting the annihilation photons being detected almost at the same time by two detectors. Each coincidence event reflects a line in space that links the detector pair and contains the occurrence of the positron emission (the LOR). A sinogram is a form in which the raw PET data are organized. The reconstruction