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Review Article

Model-based Iterative Reconstruction: A Promising Algorithm for Today's Computed Tomography Imaging

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ABSTRACT

Because of its fast image acquisition and the rich diagnostic information it provides, computed tomography (CT) has gradually become a popular imaging modality among clinicians. Because CT scanners emit x-rays, the increased use of CT in clinical applications inevitably leads to increased medical radiation dose to the population. Because of the well-known cancer-inducing effects of high dose x-ray radiation, this increased dose has caused concerns among policy makers and general public that CT patients may be at a higher risk of developing cancer. Over the years, CT manufacturers have developed a variety of strategies to address this issue, the latest being a model-based iterative reconstruction (MBIR) algorithm. MBIR is an advanced CT algorithm that incorporates modeling of several key parameters that were omitted in earlier algorithms to reduce computational requirement and speed up scans. This review article examines the latest literature in the clinical CT field and discusses the general principles of MBIR, its dose and noise reduction potentials, its imaging characteristics, and its limitations. MBIR algorithm and its application in today's CT imaging will greatly reduce the radiation dose to patients and improve image quality for clinicians.

RÉSUMÉ

En raison de la rapidité de l'acquisition de l'image et de la richesse de l'information diagnostique qu'elle offre, la tomographie par ordinateur a rapidement gagné en popularité chez les cliniciens. Puisque les appareils de tomographie émettent des rayons X, leur utilisation croissante dans les applications cliniques conduit inévitablement à une augmentation de la dose de radiation médicale dans la population. En raison des effets cancérigènes bien connus des doses élevées de rayons X, cette dose accrue a soulevé des craintes chez les décideurs et le grand public du fait que les patients soumis à la tomographie par ordinateur puissent présenter un risque plus élevé de souffrir d' un cancer. Au fil des années, les fabricants d'appareils de tomographie par ordinateur ont élaboré différentes stratégies pour aborder cet enjeu, le plus récent étant un algorithme de reconstruction itérative basée sur un modèle (model-based iterative reconstruction - MBIR). Le MBIR est un algorithme avancé de tomographie par ordinateur qui intègre la modélisation de plusieurs paramètres clés omis dans les algorithmes précédents afin de diminuer les exigences de calcul et accélérer le balayage. Cet article recense les plus récents articles publiés dans le domaine de la tomographie clinique et aborde des principes généraux du MBIR, de son potentiel de réduction de la dose et du bruit, de ses caractéristiques d'image et de ses limites. L'algorithme MBIR et son application en imagerie tomographique permettra de diminuer fortement la dose de rayonnement pour les patients et d'améliorer la qualité des images pour les cliniciens.

Keywords: MBIR; model-based iterative reconstruction; CT; computed tomography; radiation dose

Introduction

In 2006, 67 million computed tomography (CT) examinations were performed in the United States alone [1]. The result is an increase of medical radiation dose received as a percentage of the total radiation exposure from 15% in the early 1980s to almost 50% in 2006 [1]. Based on a model known as Biological Effects of Ionizing Radiation [2], Berrington de Gonzalez et al [3] predicted that 29,000 future cancers in the United States will be caused by CT scans performed in the year 2007 alone. Echoing this sentiment, Brenner and Hall [4] estimated that 1%–2% of all cancers in America are caused by CT examinations. In the area of pediatric CT, Pearce et al [5] reported that the risk of leukaemia and brain cancer tripled in children after receiving cumulative doses of about 50 and 60 mGy, respectively.

Because of these concerns associated with ionizing radiation exposure, several dose reduction methods have already been developed by CT manufacturers. The popular techniques that are currently in clinical use include dual-source CT scanners, adaptive noise reduction filters, tube current

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modulation, and prospective cardiac electrocardiography (ECG) modulation, among others [6]. More recently, the focus of CT dose reduction has been shifted toward iterative reconstruction (IR) algorithms, a new frontier aimed at further reducing the radiation exposure received by patients.

Traditionally, CT images have been produced using analytical reconstruction algorithms such as filtered back projection (FBP) or convoluted back projection instead of IR algorithms because of their simple mathematical computation requirement. Most techniques involving these analytical algorithms neglect the cone-beam geometry of the measured data and depend on false assumptions, which compromise the truthfulness of output images. For example, in FBP and convoluted back projection algorithms, the x-ray source and the individual cell on the detector in a CT scanner are considered infinitely small. Each voxel also has no shape or size. To construct high-quality images, IR algorithms have been used to address some of the weaknesses associated with traditional algorithms. Over the past few years, several IR algorithms have emerged in clinical CT applications. A list of these statistical and model-based IR algorithms can be found in Table 1.

Iterative Reconstruction (IR)

Unlike analytical reconstruction that uses simple mathematical assumptions of a CT imaging system, statistical IR is based on the statistics of random fluctuations in sinogram measurements, also known as the two-dimensional array of raw data containing CT projections [7]. Instead of manipulating data to conform to analytical reconstruction models, statistical and model-based methods try to incorporate a data obtaining, comparing, and updating cycle into the reconstruction process that improves the diagnostic accuracy of the output CT images. There are three major components of an IR algorithm. First, artificial object data from estimation or a standard volume of a similar object are created. Second, these estimated raw data are compared with the real measured data from the imaging system. Third, the difference between these two data sets is projected back to the estimation step for future correction. This entire cycle continues until the difference between the estimated and measured data is within an acceptable range. An example of a statistical IR algorithm, sometimes known as a hybrid IR algorithm because of its ability to blend with FBP, is called adaptive statistical iterative reconstruction (ASIR). It models photons and electric noise in the CT system, and it is not computationally expensive or time-consuming to perform clinically on today's computer system [8]. The basic workflow for reconstructing CT images using either an FBP or an ASIR algorithm is shown in Figure 1.

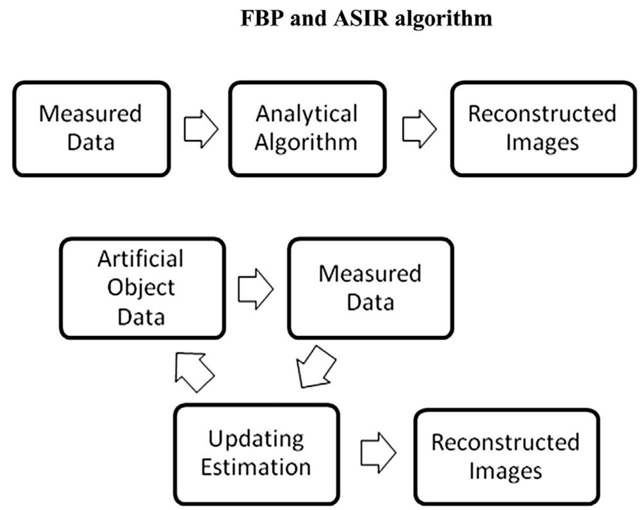

Figure 1. The basic workflow of an FBP (top) and ASIR algorithm (bottom).

More recently, model-based iterative reconstruction (MBIR), also known as pure IR algorithm, has been shown to significantly improve image quality while reducing noise and artifacts in multislice CT scans during initial tests [9, 10]. In MBIR, images are reconstructed by minimizing the objective function incorporated with an accurate system model, a statistical noise model, and a prior model [11]. The system model deals with the nonlinear, polychromatic nature of x-ray tubes by modeling the photons in the measured data set. The statistical noise model takes into consideration the size of an x-ray tube focal spot and the three-dimensional shape of detectors. The prior model is a regularization algorithm that corrects unrealistic situations during reconstruction to speed up the process. A basic workflow of an MBIR algorithm is summarized in Figure 2.

Table 1
A List of Statistical and Model-based Iterative Reconstruction Algorithms Developed by Major Computed Tomography Manufacturers Listed in Alphabetical Order

Manufacturer	Statistical IR	Model-based IR
General Electric	ASiR	Veo
Philips	iDose	IMR
Siemens	IRIS	SAFIRE
Toshiba	AIDR 3D (integrated)	AIDR 3D (integrated)

IR, iterative reconstruction.

Dose Reduction and Image Characterization in CT Applications

All literature surveyed in this review conducted their studies in a typical clinical setting, with eligible patients

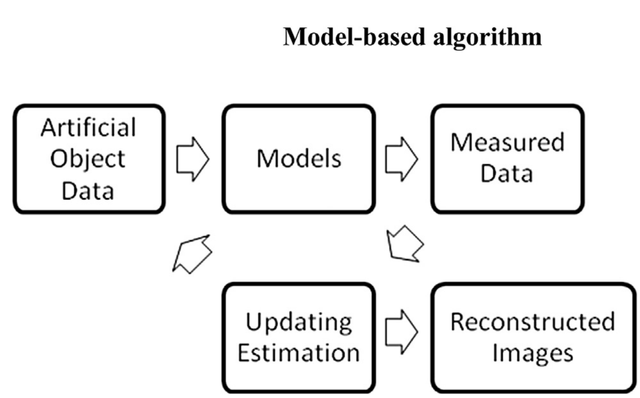

Figure 2. The basic workflow of an MBIR algorithm.