REDUCING STAIRCASING ARTIFACTS IN SPECT RECONSTRUCTION BY AN INFIMAL CONVOLUTION REGULARIZATION[*]

Zhifeng Wu

School of Mathematics, Guangdong Provincial Key Lab of Computational Science
Sun Yat-sen University, Guangzhou 510275, P. R. China
E-mail: whutxxz@163.com

Si Li

School of Data and Computer Science, Guangdong Provincial Key Lab of Computational Science
Sun Yat-sen University, Guangzhou 510275, P. R. China
E-mail: reesiloveu@163.com

Xueying Zeng

School of Mathematical Sciences, Ocean University of China, Qingdao 266100, P. R. China
E-mail: zxying@ouc.edu.cn

Yuesheng Xu

School of Data and Computer Science, Guangdong Provincial Key Lab of Computational Science
Sun Yat-sen University, Guangzhou 510275, P. R. China
Department of Mathematics, Syracuse University, Syracuse, NY 13244, USA
E-mail: yxu06@syr.edu

Andrzej Krol

Department of Radiology and Department of Pharmacology, SUNY Upstate Medical University
Syracuse, NY 13210, USA

Abstract

The purpose of this paper is to investigate the ability of the infimal convolution regularization in curing the staircasing artifacts of the TV model in the SPECT reconstruction. We formulate the problem of SPECT reconstruction with the infimal convolution regularization as a convex three-block optimization problem and characterize its solution by a system of fixed-point equations in terms of the proximity operator of the functions involved in its objective function. We then develop a novel fixed-point proximity algorithm based on the fixed-point equations. Moreover, we introduce a preconditioning matrix motivated by the classical MLEM (maximum-likelihood expectation maximization) algorithm. We prove convergence of the proposed algorithm. The numerical results are included to show that the infimal convolution regularization is capable of effectively reducing the staircasing artifacts, while maintaining comparable image quality in terms of the signal-to-noise ratio and coefficient recovery contrast.

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1. Introduction

The goal of this article is to investigate the ability of the infimal convolution of functionals with the first- and second-order derivatives, denoted by ICTV, to cure staircasing artifacts in SPECT reconstruction. We develop a novel fixed-point proximity algorithm to solve the resulting three-block optimization problem, motivated by the fixed-point framework studied in [16, 17, 21, 22].

Single photon emission computerized tomography (SPECT) is an important medical imaging tool for studying functional characteristics of human bodies. In contrast, computed tomography (CT) or magnetic resonance imaging (MRI) provides only structure information of human bodies. For this reason, SPECT has become one of the most important techniques for detection and evaluation of coronary artery diseases. Other clinical applications of SPECT include detecting, staging and monitoring response to cancer therapy, pulmonary ventilation/perfusion scans, renal scans, and bone scans [32]. Clinical SPECT data are often severely corrupted by Poisson noise due to low tracer dosage and short acquisition time. A widely used algorithm today for clinical SPECT image reconstruction is the ordered-subset expectation maximization algorithm (OSEM) [13], which has greatly improved the convergence speed compared to the original maximum-likelihood expectation maximization algorithm (MLEM) [15, 29]. However, one disadvantage of OSEM is that the noise in the reconstructed image increases with iterations, and the resulting noise level often makes the reconstructed image clinically unacceptable. Therefore, it is stopped prematurely and post-filtering should be applied [20].

As an alternative to OSEM, maximum *a posteriori* (MAP) in a Bayesian framework was proposed [11], and has gained wide interest since then. MAP incorporates a regularization term into the objective function, which assembles the *a priori* knowledge of the image. The total variation (TV) regularization is capable of suppressing noise effectively, and at the same time capturing sharp edges [26]. Hence the TV semi-norm has been widely used as a regularizer in SPECT reconstruction [3, 14, 23, 25, 27]. The TV method works quite well when the true object contains only piecewise constant regions. However, when the true object is smooth, the use of the TV regularization often results in patchy, cartoon-like images, known as staircasing artifacts [31]. In the past two decades, considerable research interest was devoted to overcoming this side effect of the TV regularization. Several variants of the TV regularization were proposed. Chan et al. introduced in [8] a fourth-order non-linear filter. A generalized total variation model, known as TGV, was proposed by Bredies et al. in [4]. A recent work [19] studied effective noise-suppressed and artifact-reduced reconstruction of SPECT data using a higher-order TV regularization and the resulting optimization problem was solved by using a preconditioned alternating project algorithm.

The first issue that we study in this paper is to investigate the suitability of using the ICTV regularization in SPECT reconstruction. The ICTV regularization, suggested by Chambolle and Lions in [7], combining the total variation of the image with the total variation of its gradient, showed a possibility of reducing staircasing artifacts in mathematical imaging. Whether it is suitable for SPECT reconstruction remains unclear. Studying this issue is the first objective of this paper. The reason that we believe that ICTV is able to reduce staircasing artifacts in SPECT reconstruction may be explained in two ways. The null space of the ICTV functional is much larger than that of the TV functional. We expect that the ICTV regularization would be more likely to produce smoother reconstruction than the TV regularization, and the staircasing artifacts would be alleviated. We can also view the ICTV functional as