Novel methods for metal artifact reduction in x-ray tomography

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Abstract— **Metals cause severe image artifacts in x-ray tomography, and accordingly a number of reduction approaches have been developed. We review our recently proposed metal artifact reduction (MAR) approaches for computed tomography (CT) that is computationally more efficient than a fully iterative reconstruction method, but at the same time achieves superior image quality to the interpolation-based in-painting techniques. Our proposed MAR method, an image-based artifact subtraction approach, utilizes an intermediate prior image reconstructed via pseudo-discrete algebraic reconstruction technique (PDART) to recover the background information underlying the high density objects. Additional approaches to tomosynthesis and other applications would be included in the conference presentations.**

Keywords—Computed tomography, metal artifact, image reconstruction

I. INTRODUCTION

Conventional MAR methods are based on sinogram in-painting. Iterative reconstruction methods are also in active research. In-depth mathematical analysis of metal artifact formulation is also being studied. Metal artifacts characterized by beam hardening and photon starvation can serve as guides to improving the existing MAR techniques. Additionally, hybrid MAR methods also emerged to combine and emphasize the benefits offered by individual MAR approaches.

Our earlier proposed MAR method is classified as a hybrid technique that performs artifact subtraction in the image domain [1]. A major part of the earlier proposed MAR method is the reconstruction of a prior image from uncorrupted projections via total variation minimization (TVM) algorithm [2]. The prior image provides realistic estimate of the metal-void regions in the sinogram. Although this takes relatively long time due to iterative reconstruction nature of TVM algorithm, the strategy was shown to achieve higher quality images than conventional interpolation-based MAR images. High quality prior images such as those that closely resemble a metal-free or an artifact-free image will indeed be more effective in mitigating artifacts. However, producing an artifact-free or even an almost artifact-free image requires heavy computations.

To address this issue, we have proposed in another work [3] an iterative reconstruction approach motivated by Discrete Algebraic Reconstruction Technique (DART), originally proposed to yield an acceptable prior image in the first few iterations [4]. We refer to our proposed reconstruction technique as Pseudo-DART (PDART) for it does not entirely follow the DART procedures but only incorporates the idea of reconstruction and discretization in a single process.

DART is a heuristic iterative technique that can render a high quality image reconstruction from limited projection data such as limited angular range, few view projections, and truncated projections by utilizing a prior information of the discreteness of grey values of the scanned object. DART has been shown to be most effective in binary image reconstruction especially in the field of electron tomography, but has also been applied to non-binary image reconstruction in CT simulation studies.

Our proposed PDART approach for prior image reconstruction also involves a sequence of conventional iterative reconstruction and discretization. Similarly, the main PDART procedure starts after getting an initial algebraically reconstructed image. Since prior information of the scanned object is not always accessible, the discretization in PDART utilizes a histogram that is extracted from the initial image to determine the discrete bin values. All image pixels are then updated in every PDART iteration that results in a "continuous" prior image which is used as an intermediate image in our proposed MAR approach. Also, it is important to note that PDART reconstructs prior images from incomplete or high-density-material-free projections in MAR. We focus on the summarized results of the PDART in this article.

II. METHODS

PDART is a combination of TVM reconstruction algorithm and discretization in a single reconstruction iteration. A schematic diagram of PDART is shown in Fig. 1. Specifically, PDART is an iterative sequence of POCS, TV, and discretization steps. Similar to DART, our proposed PDART performs a number of initial ARM iterations prior to the main PDART process. In this study, 10 initial TVM and 5 PDART iterations were performed to generate the PDART prior image.

The additional discretization step assumed that a given image f is made up of l number of discrete d bin values.

A maximum of 5 discrete bin values is efficient to discretize any non-binary image. In this investigation, discretization was implemented using the following procedure:

a.) Extraction of histogram. A histogram was extracted to plot the pixel value distribution of an image.

b.) Identification of discrete bin values. The maximum or peak values in the histogram for each material were chosen as the discrete bin values.

c.) Classification of image pixels to discrete bin values. Image pixels were assigned to the nearest discrete bin values. By doing so, the discretized image only contains dl values.

Henceforth, IMAR-TVM and proposed IMAR-PDART refer to our image-based metal artifact reduction scheme incorporating conventional TVM and proposed PDART as the prior image iterative reconstruction algorithms, respectively.

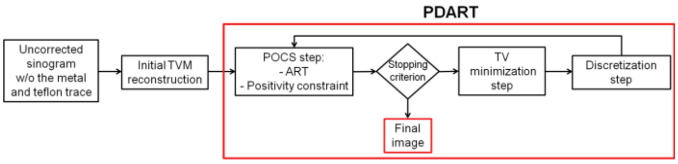

Fig. 1 Flow diagram of the proposed PDART scheme. PDART process was implemented after an initial number of conventional TVM iterations. This was followed by a sequence of POCS, TV, and discretization steps until a prior image was reconstructed after 5 PDART iterations.

III. Results

Uncorrected and MAR images of the phantom 1 are shown in the 1st row of Fig. 2. Uncorrected image, Fig. 2 (a), exhibited the distinctive streak artifacts due to the metal object. Although all MAR schemes in this study adequately suppressed the primary streak artifacts, slight beam hardening along with a conspicuous dark region encircling both high density inserts were introduced in the standard MAR image, Fig. 2 (b). Artifacts were clearly minimized after IMAR-TVM and proposed IMAR-PDART schemes as shown in Fig. 2 (c) and Fig. 2 (d), respectively. Based from the SSIM values of Phantom 1 summarized in Table 2, IMAR-TVM outperformed the other MAR schemes. However, proposed IMAR-PDART had also been shown to be as effective as IMAR-TVM in reducing metal artifacts in various areas of the image.

Uncorrected image of the phantom 2 in Fig. 2 (e) demonstrated an increase in artifact degradation, particularly streak and beam hardening artifacts, characterized by the addition of high density materials. Likewise, standard MAR scheme, Fig. 2 (f), produced more artifacts including the dark region surrounding each high density object. However, IMAR-TVM and proposed IMAR-PDART remarkably reduced these artifacts and gave visually comparable images as presented in Fig. 2 (g) and Fig. 2 (h), respectively.

IV. Conclusions

Metal artifacts threaten the reliability and accuracy of CT images. With the emergence of hybrid MAR techniques, advantages of different MAR techniques can be combined to produce more superior images than conventional individual MAR approaches. Our proposed IMAR-PDART scheme utilized a combination of inpainting-based and iterative reconstruction methods. Specifically, we introduced a pseudo-DART (PDART) approach as the iterative reconstruction algorithm and successfully reconstructed acceptable prior images after 5 iterations in both simulation and real data studies. In initial iterations, proposed PDART produced better quality prior images compared to TVM equivalent images. Our proposed IMAR-PDART considered the effect of all high density objects in the scanned object. In terms of image quality of the recovered MAR images, proposed IMAR-PDART outperformed the standard MAR approach and showed comparable image quality to IMAR-TVM which utilized high quality TVM prior images reconstructed after hundreds of iterations.

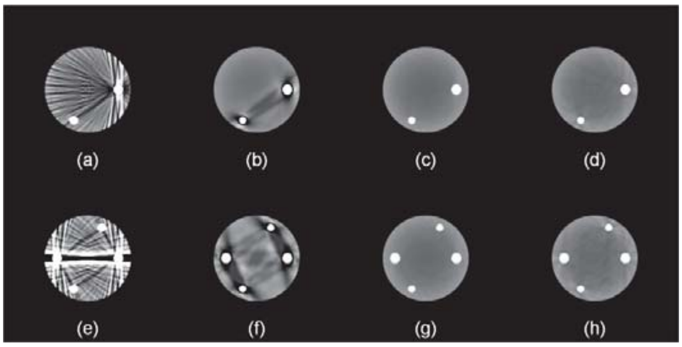

Figure 2. (a & e) Uncorrected, (b & f) standard MAR, (c & g) IMAR-TVM, and (d & h) proposed IMAR-PDART images of Phantom 1 and Phantom 2 are provided in the 1st and 2nd rows, respectively.

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