A Metal Artifact Reduction Method with Bone Segmentation for CBCT Images

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Abstract. Nowadays, CBCT images become popular and are widely used in the dental diagnosis. The image quality is related to the accuracy of diagnosis and treatment. When metal objects such as the dental implants are present in CBCT scanning, the metal artifacts will appear and decrease the image quality. In order to reduce the metal artifacts, this paper proposes a metal artifact reduction method for the dental CBCT images. This method is based on inpainting the sinogram and mainly has three innovations. First, this method forward-projects only the region around the metal implants. Second, the bones in the forward projection region are segmented and their intensity values are set to zero before the forward projection. Finally, this method computes an image to directly correct the original CBCT image, this correction image is the back projection of the difference between the interpolated sinogram and the original sinogram. The proposed method reduces the metal artifacts and improves the image quality, it may potentially increase the diagnosis value of the CBCT images corrupted by the metal artifacts.

1. Introduction
Cone beam computed tomography (CBCT) imaging is frequently used in maxillofacial surgical applications because it has a low radiation dose, small volume, and high resolution [1,2]. CBCT images are often corrupted when a patient has metal objects such as the metal implants. When the metal objects such as the dental implants are present in the CBCT scans, the metal artifacts appear as the bright and dark shadows and streaks around the metal objects in the CBCT images. Metal artifacts reduce the image quality and decrease the diagnosis value of the CBCT images.

Metal artifacts are caused by several negative effects such as photon starvation, beam hardening, and photon scattering. Projection data before reconstruction (RAW data) are degraded by these effects and many inpainting-based metal artifact reduction approaches are proposed. Kalender et al. proposed a simple algorithm using linear interpolation [3]. Wang et al. calculated 3D coordinates of metal objects and apply a bilinear interpolation to correct the projection data [4]. Bal et al. segmented the image into different tissue classes and used the sinogram of the tissue-class model to correct the original sinogram [5]. Meyer et al. introduced a new type of projection completion technique, called normalized metal artifact reduction (NMAR), that normalizes the original projection data to prior image projection data [6]. They also proposed frequency split metal artifact reduction (FSMAR) method based on the NMAR to preserve edges and anatomical details [7]. Park et al. proposed using an artifact-reduced prior image to complete the sinogram for the dental CT images [8].

Most inpainting-based MAR methods need projection RAW data and reconstruction parameters, but these data and parameters are usually confidential to users. In this paper, the proposed MAR algorithm reduces metal artifacts based only on the reconstructed CBCT images. The sinogram is the Radon...
transform of a CBCT image. Different from other inpainting-based MAR methods, the proposed MAR method has three innovations: (1) this method only forward-projects the region around the metal implants; (2) the bones in the forward projection region are segmented and their intensity values are set to zero before the forward projection; (3) this method computes an image to directly correct the original CBCT image, this correction image is the back projection of the difference between the interpolated sinogram and the original sinogram. The proposed MAR method and the results are described in the following sections.

2. Methods
The proposed MAR algorithm consists of four steps: (1) metal segmentation, (2) pre-processing, (3) sinogram correction, (4) original image correction. The flow chart of the proposed MAR algorithm is shown in figure 1. The method works on the reconstructed CBCT images but the projection RAW data are not used. The sinograms are computed by Radon transform. The sinogram inpainting is based on the linear interpolation (LI) MAR method [3]. The following sections are the steps in details.

2.1. Step 1: Metal Segmentation
The metal image $I_m$ is segmented by simple thresholding from the original image $I_{ori}$. The metal image only contains the metal part, all pixels whose intensity Hounsf ield Unit (HU) values are lower than the metal threshold (3000 HU usually chosen [7]) are set to zero. The metal trace $P_m$ is the binary image of the forward-projection of $I_m$ and is used in the sinogram correction step.

2.2. Step 2: Pre-processing
Metal artifacts are always around the metal implants. Forward-projection and back-projection are time-consuming and their time complexities are in direct proportion to the size of the original image. In order to improve the efficiency, the proposed MAR algorithm only forward-project the region around the metal implants as $I_{fpr}$ shown in figure 1. The forward-projection region $I_{fpr}$ is computed by expanding outward 50 pixels of the minimum bounding rectangle (MBR) of $I_m$. It is worth mentioned that if the expanded MBR is beyond the field of view (FOV) of the CBCT, $I_{fpr}$ is the intersection set of the expanded MBR and FOV as shown in figure 1.

For the inpainting-based MAR method, the interpolation results are accurate in the angle where the bones do not interfere with the metal projection [9]. When the bones interfere with the metal projection, the interpolation results may loss edge information which results in secondary artifacts in the processed image [9]. Therefore, the proposed method segments the bones from the original image in the forward-projection region and sets their HU values to zero. The k-means clustering method [10] was used to separate the original image in the forward-projection region to the air, soft tissue (water included) and bone as $I_{ts}$ shown in figure 1. The initial centroid HU values of the air, soft tissue and bone are set as -500, 500 and 1500 respectively and 10-20 iterations are sufficient to determine these centroid HU values.

After completion of clustering, HU values of the bones inside the forward-projection region and all pixels outside the forward-projection region are set to zero, and HU values of the air and soft tissue inside the forward-projection region are kept same as original image as $I_{vm}$ shown in figure 1.

2.3. Step 3: Sinogram Correction
The sinogram $P_{ori}$ is the forward-projection of $I_{vm}$ computed by the Radon transform. The state-of-the-art LI MAR method presented by Kalender et al. [3] is employed to correct the sinogram $P_{ori}$ based on the metal trace $P_m$, the sinogram $P_{LI}$ is the correction result. Finally, compute the difference sinogram $P_{diff}$ of $P_{ori}$ and $P_{LI}$ as shown in equation (1).

\[ P_{diff} = P_{LI} - P_{ori} \]  

(1)
2.4. Step 4: Original Image Correction

The correction image $I_{cor}$ is the back-projection of $P_{diff}$ computed by the inverse Radon transform and the MAR image is computed as shown in equation (2).

$$I_{mar} = I_{ori} + I_{cor}$$

For most of inpainting-based MAR methods, the MAR image is the back-projection of the correction sinogram. Because the Radon transform is based on the Fourier transform, it is a linear and time-invariant system. The proposed MAR algorithm employs the back-projection of the difference of the correction sinogram and the sinogram of the HU value modified image to correct the original corrupted CBCT image. On the one hand, the difference sinogram $P_{diff}$ has less valid data than the correction sinogram $P_{LI}$, therefore computing the back projection of $P_{diff}$ uses less time than computing the back-projection of $P_{LI}$. On the other hand, if the MAR image is formed by the back-projection of the correction sinogram $I_{cor}$ inside the forward projection region $I_{fpr}$ and the original image outside the forward-projection region $I_{fpr}$, the MAR image would be discontinuous on the boundary of the forward-projection region. Our proposed method avoids this discontinuous phenomenon.

Figure 1. The flow chart of proposed MAR algorithm consisting of four steps: (1) metal segmentation, (2) pre-processing, (3) sinogram correction, (4) original image correction.
3. Result and Discussion
In order to verify the performance of the proposed MAR method, the MAR images processed by the proposed method were compared with those processed by the LI MAR method [3] as shown in figures 2 and 3. Although the proposed MAR method only processes the region around the metal implants, the metal artifacts were reduced by proposed method as similar as the LI MAR method or even better in some places. As the arrows shown in figures 2 and 3, the LI MAR method introduces new artifacts and the proposed MAR method performs well in these regions. As the comparison of figure 2(e) and figure 2(f), MAR results of the proposed method is more natural than those of the LI MAR method around the edges of the metal implants. In comparison of figure 3(e) and figure 3(f), because the proposed method segments the bones and sets their HU values to zero before the forward-projection, the bones are better preserved by the proposed MAR method.

In order to evaluate the efficiency of the proposed MAR method, 20 groups of CBCT datasets with metal implants were randomly collected for test, and the CBCT images containing more than 200 metal pixels whose HU values are higher than metal threshold (3000HU) were used for the test. There are 2329 images tested.

The CBCT datasets were acquired using the MEYER SS_X9010DPro-3DE CBCT system (HEFEI MEYER OPTOELECTRONIC TECHNOLOGY INC., China) with current 9-10 mA and voltage 80-90 KV and image size 480 × 480. The proposed MAR method and the LI MAR method were implemented using C++ codes on a Lenovo desktop (Win 10, Intel Core i7-9700K 3.60 GHz, 16 GB RAM).

It took 191.269 ± 7.194 ms by the proposed MAR method to process an image, much less than the time 305.380 ± 2.067 ms that the LI MAR method used to process an image. The proposed MAR method demonstrated high computational efficiency in that it forward-projected only the region around the metal. Although the proposed MAR method involves the bone segmentation step, it is still much more efficient than the LI MAR method in computation.

| Original | LI MAR | Proposed MAR |
|----------|--------|--------------|

Figure 2. Patient with one metal implant. The original CBCT image (a), the image (b) (LIMAR) and the image (c) by proposed MAR method from left to right. The second row are the partial enlarged portions (d), (e), (f) of (a), (b), (c) respectively in the first row.
4. Conclusions
In this paper, a metal artifact reduction method with bone segmentation for dental CBCT images is proposed. The proposed MAR algorithm is based on the linear interpolation (LI) MAR method [3] to correct the sinogram. In contrast, the proposed MAR algorithm forward-projects only the region around the metal implants to decrease the computational cost and segments the bones to reduce the interpolation errors caused by the bones. In addition, to avoid the discontinuities around the boundary of the forward-projection region of the MAR image and further to reduce the computational cost, the proposed MAR algorithm back-projects the difference of the correction sinogram and the original sinogram rather than the correction sinogram. The proposed MAR algorithm reduces the metal artifacts and improves the image quality in comparison with LI MAR method. Our future work will focus on combination of current method with image processing in spatial domain.

Acknowledgments
This work was supported by Guangdong Higher Education Key Platform and Research Project (No. 2020ZDZX3039).

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