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Sinogram fusion-based metal artifact correction method

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Abstract: To solve the problem that metal artifacts severely damage the clarity of the organization structure in computed tomography (CT) images, a sinogram fusion-based metal artifact correction method is proposed. First, the metal image is segmented from the original CT image by the pre-set threshold. The original CT image and metal image are forward projected into the original projection sinogram and metal projection sinogram, respectively. The interpolation-based correction method and mean filter are used to correct the original CT image and preserve the edge of the corrected CT image, respectively. The filtered CT image is forward projected into the filtered image sinogram. According to the position of the metal sinogram in the original sinogram and filtered image sinogram, the corresponding sinograms P_M^D (in the original sinogram) and P_M^C (in the filtered image sinogram) can be acquired from the original sinogram and filtered image sinogram, respectively. Then, P_M^D and P_M^C are fused into the fused metal sinogram P_M^F according to a certain proportion. The final sinogram can be acquired by fusing P_M^F, P_M^D and the original sinogram P^O. Finally, the final sinogram is reconstructed into the corrected CT image and metal information is compensated into the corrected CT image. Experiments on clinical images demonstrate that the proposed method can effectively reduce metal artifacts. A comparison with classical metal artifacts correction methods shows that the proposed metal artifacts correction method performs better in metal artifacts suppression and tissue feature preservation.

Key words: metal artifacts; interpolation-based method; sinogram fusion-based; computed tomography (CT) image

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Computed tomography (CT) has been widely used in practice since its invention in the 1970s. In the absence of metal, the CT imaging system can provide clear images with high-resolution anatomical information. However, some metal objects are present in the scanning field, such as dental implants, internal fixation and prosthesis et al. Some streak artifacts (metal artifacts) emerge in reconstructed CT image by using the filter back projection (FBP) algorithm with the raw projection data. The metal artifacts greatly deteriorate image quality and seriously affect the diagnostic effects. Therefore, researchers have proposed some metal artifacts correction methods to reduce these artifacts and improve image quality.

These metal artifact correction methods can be roughly grouped into the following three categories; namely the interpolation-based correction method[1-9], iterative reconstruction correction method[10-12] and hybrid correction method[13]. The interpolation-based correction method replaces the unreliable data in the corrupted metal trace with surrogate data obtained by using interpolation techniques[8]. In the interpolation-based correction techniques, the linear interpolation is the simplest and earliest interpolation algorithm[1]. Besides the linear interpolation, there is the polynomial interpolation algorithm[2], wavelet interpolation[3], normalized interpolation[4], etc. The most crucial problem for the interpolation-based correction method is the additional artifacts for the corrected images. The iterative reconstruction correction method can effectively remove the metal artifacts in the original image. However, low efficiency limits its use. The hybrid correction method[13] is the integration of the interpolation-based correction method and iterative reconstruction correction method. The integrated method possesses the advantages of the interpolation-based correction method and iterative reconstruction correction method. The fatal shortcoming of the hybrid method is the function allocation problem between the interpolation-based correction method and iterative reconstruction correction method.

To remove the metal artifacts in the CT image, in this paper, a sinogram fusion-based metal artifact correction method is introduced to correct the CT image.

1 Materials and Methods

The proposed method is comprised of the following four steps, namely the image segmentation and interpolation-based method correction, mean filter, sinogram fusion, and back-projection reconstruction and metal information compensation. Fig. 1 is the flowchart of the proposed algorithm.

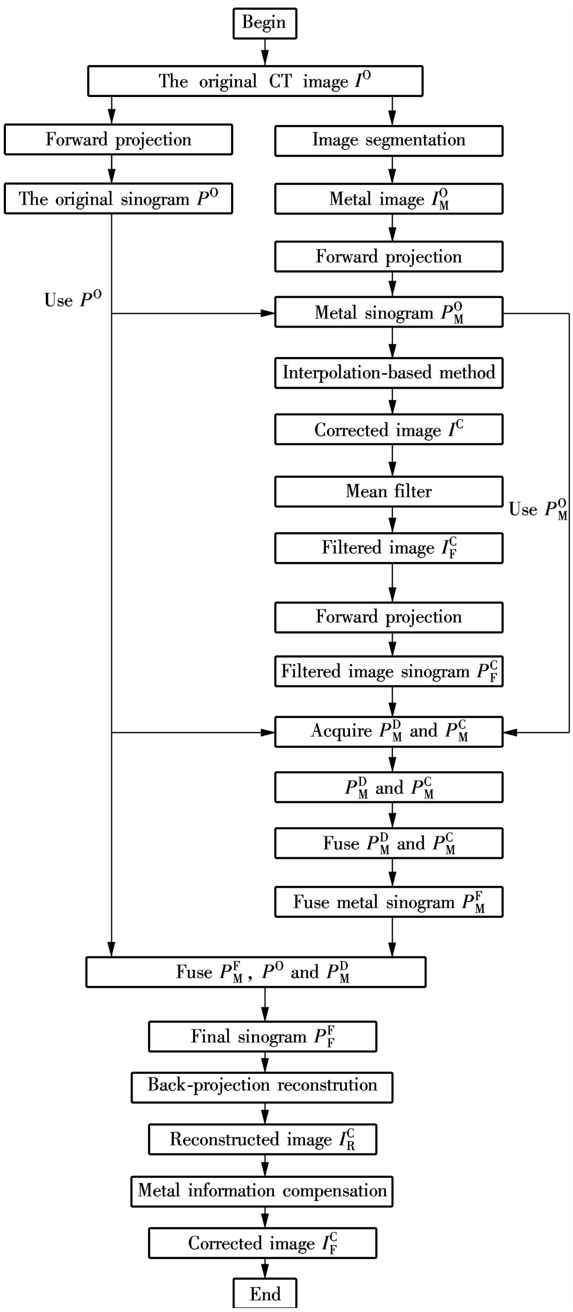


Fig. 1 Flowchart of the proposed algorithm

1.1 Image segmentation and interpolation-based method correction

In the first step, the original CT image I^O is segmented into metal image I_M^O and no-metal image I_N^O by the pre-set threshold (The value is 2 000 in the experiments). Then, the original CT image I^O and metal image I_M^O are forward projected into the original projection sinogram P^O and metal projection sinogram P_O^M, respectively. Finally, the interpolation-based correction method[1] is used to correct the original CT image I^O in corrected image I^C.

1.2 Mean filter

During the stage of applying the interpolation-based correction method when correcting the original CT image I^O, some new artifacts are introduced in the corrected CT image I^C.

As a result, serious loss of edge structure near the metal can be seen from the corrected CT image I^C. Therefore, to preserve the edge structure and suppress the new introduced artifacts near the metal in the corrected CT image I^C, the mean filter is applied in the corrected CT image I^C. The pixel gray values $V_F(i,j)$ $(i = 1, 2, \ldots, M;\ j = 1, 2, \ldots, N$, where M and N denote the number of rows and columns in the CT image, respectively.) in the filtered CT image are the average pixel gray values around the pixel (i,j) in the corrected CT image I^C.

$$V_F(i,j) = \frac{\sum_{m=-d}^{d} \sum_{n=-d}^{d} v(i+m, j+n)}{K} \tag{1}$$

where K is the pixel number around the pixel (i,j) in the corrected CT image I^C; d is equal to 20 for the experiments in this paper. $v(i+m, j+n)$ is computed as

$$v(i+m, j+n) = \begin{cases} v_p(i+m, j+n) & |b_p(i+m, j+n) - b_p(i+j)| > T \\ 0 & |b_p(i+m, j+n) - b_p(i,j)| \leqslant T \end{cases} \tag{2}$$

where T should be properly selected to preserve the edge structure and suppress the newly introduced artifacts ($T = 200$ in the experiments); I_F^C denotes the filtered image.

1.3 Sinogram fusion

After mean filtering, the filtered image I_F^C is forward projected into a filtered sinogram P_F^C. First, according to the position of metal sinogram P_M^O in the original sinogram P^O and filtered image sinogram P_F^C, the corresponding part P_M^D in the original sinogram P^O and P_M^C in the filtered image sinogram P_F^C can be acquired from P^O and P_F^C, respectively. Then, the two sinograms P_M^D and P_M^C are fused into the fused metal sinogram P_M^F according to a certain proportion. Finally, the final sinogram P_F^F can be acquired by fusing the sinograms P_M^F, P^O and P_M^D.

1.4 Back-projection reconstruction and metal information compensation

After acquiring the final sinogram P_F^F, the artifacts-reduced image I_R^C is obtained by reconstructing P_F^F with the filter back-projection reconstruction algorithm. Finally, the final corrected image I_F^C can be obtained by compensating the metal objects segmented from the original image in the reconstructed image I_R^C.

2 Experiments and Results

To evaluate the performance of the proposed correction method, the experiments are performed on clinical images. In this section, the effects of fusion ratios on the corrected images and comparison with the interpolation-based correction method are provided.

2.1 Corrected images with different ratios

In order to demonstrate the effect of fusion ratio on the corrected images, Fig. 2 shows the original image and corrected images with different fusion ratios. Fig. 2 (a) is the original image. Figs. 2 (b) to (f) are the corrected images with different fusion ratios. As can be seen from Fig. 2 (a), the original image involves some metal artifacts. With the increase of ratios from 0, 0.25, 0.5, 0.75 to 1, the corrected images become more and more clear.

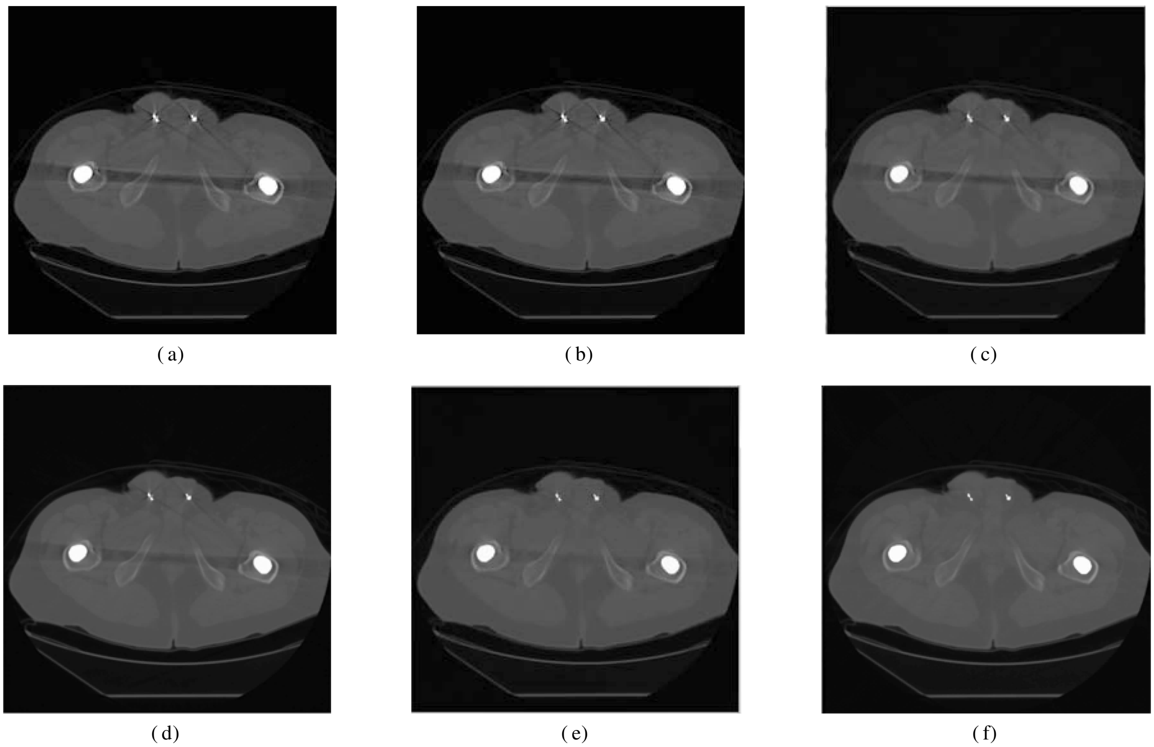


Fig. 2 Corrected images with different fusion ratios. (a) The original image; (b) $R=0$; (c) $R=0.25$; (d) $R=0.5$; (e) $R=0.75$; (f) $R=1$

2.2 Comparison with classical interpolation-based correction method

The interpolation-based correction method[1] is the classical metal artifacts correction method. Figs. 3 and 4 show the comparisons among the original images, the corrected images using the interpolation-based correction method and the corrected images using the sinogram-based fusion correction method. The original images with format DICOM in Figs. 3 and 4 come from revision radiology group[14].

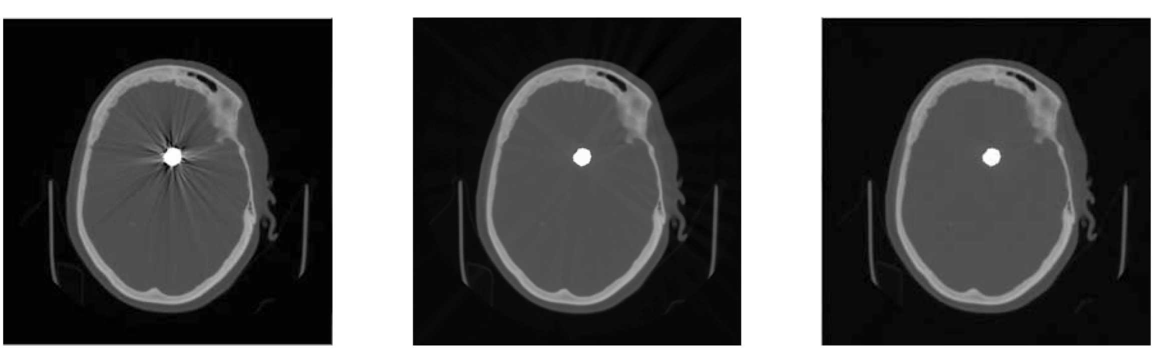
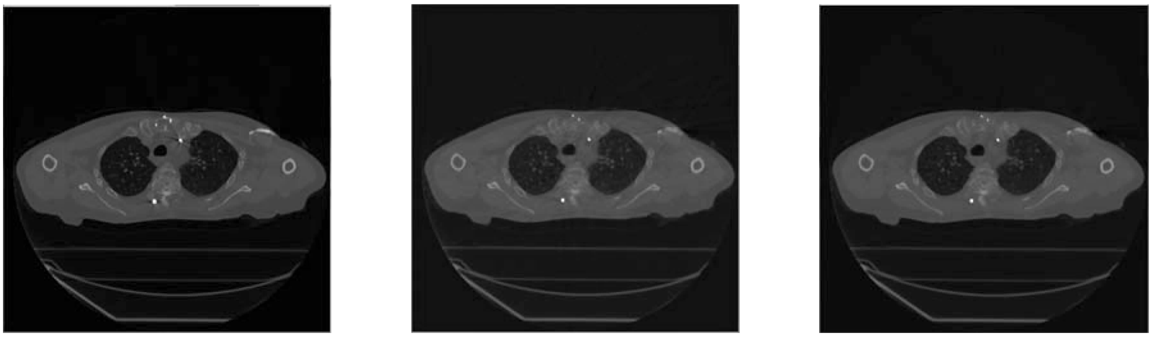


Fig. 3 The original images and corrected images of the head. (a) The original image; (b) The corrected image with the interpolation-based correction method; (c) The corrected image with the sinogram-based fusion correction method



(a) (b) (c)

Fig. 4 The original images and corrected images of the chest. (a) The original image; (b) The corrected image with the interpolation-based correction method; (c) The corrected image with the sinogram-based fusion correction method

As can be seen from subgraphs (a) in Fig. 3 and Fig. 4, the original CT images contain many metal artifacts. After using the interpolation-based correction method, the metal artifacts in subgraphs (b) of Fig. 3 and Fig. 4 have been greatly reduced. However, some artifacts remain in the corrected CT images. On the contrary, better correction effects can be seen from the subgraphs (c) in Fig. 3 and Fig. 4 using the proposed the sinogram-based fusion correction method.

3 Conclusion

In practice, the metal artifacts correction has always been a very thorny problem. To solve this problem, researchers have proposed some correction methods to remove the artifacts or reduce their influence on image quality. On the basis of the analysis of other metal artifact correction methods, we propose a sinogram-based fusion correction method to reduce the metal artifacts and compare the method with the classical metal artifact correction method. Experimental results demonstrate that the sinogram-based fusion correction method can provide better visual effects than the classical metal artifact correction method. This will lay down a solid foundation for further research and clinical application in the future.

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基于正弦图融合的金属伪影校正方法

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摘要: 针对金属伪影严重降低了 CT 图像中组织结构清晰度的问题,提出了基于正弦图融合的金属伪影校正方法. 首先,通过预先设置的阈值对原始 CT 图像进行分割,得到金属图像. 对原始 CT 图像和金属图像进行投影生成原始投影正弦图和金属投影正弦图. 使用插值校正方法校正含有金属伪影的 CT 图像和均值滤波维持校正后 CT 图像的边界. 滤波之后图像被投影成滤波图像正弦图. 根据金属图像正弦图在原始正弦图和滤波后图像对应正弦图中的位置,分别得到正弦图 P_M^D(在原始正弦图中)和 P_M^C(在滤波后图像对应正弦图中). 然后,按照一定的比例,将 P_M^D 和 P_M^C 融合成正弦图 P_M^F,并通过融合正弦图 P_M^F,P^O 和 P_M^D 得到最终正弦图. 最后,用滤波反投影重建算法将最终正弦图重建成校正之后的图像,并将金属信息补偿到校正图像上. 临床图像上的实验表明:与经典金属伪影校正方法相比,所提出的基于正弦图融合方法在金属伪影去除和组织结构特征保存方面能够得到更好的效果.

关键词: 金属伪影;基于插值校正方法;正弦图融合;CT 图像

中图分类号: TP391.41