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A New Method for Metal Artifact Reduction in CT Scan Images

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Abstract

Introduction
In CT imaging, metallic implants inside the tissues cause metal artifact that reduce the quality of image for diagnosis. In order to reduce the effect of this artifact, a new method with more appropriate results has been presented in this research work.

Materials and Methods
The presented method comprised of following steps: a) image enhancement and metal areas extraction, b) sinogram transform of original image, c) metal segments and metal traces inside the sinogram transform of original image segmented by using Fuzzy C means, d) interpolation of metal traces inside the original image sinogram and filtering, and e) adding the image of metal parts to the filtered image to obtain the corrected image.

Results
Fifty CT scan images from Alzahra Hospital in Isfahan were used to evaluate the proposed method. The proposed method was applied to images which had implants in regions such as femur, hip, tooth, brain, and stomach. The results showed an intensively reduced in metal artifact and quality improvement of images till 90% for accuracy, compared with the radiologist report.

Conclusion
The proposed method reduced the effect of metal artifact by maintaining the specification of other tissues. Furthermore, the consumed time to process the suggested algorithm in this study was less than conventional methods. For instance, the consumed time for CT image, including a metal in the femur region was about 20% of the conventional method.

Keywords: CT scan, Interpolation, Metal Artifact

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1. Introduction

In CT imaging, the attenuation coefficient of high-density objects such as surgical clips, metal prostheses in hip, dental, and other regions are much higher than that of soft tissue and skeleton map (Figure 1). Because the X-ray beam is highly attenuated by metal objects and insufficient numbers of photons reach at the detector, metal artifact are produced (Figure 2) [1]. The artifact produces white traces around of metallic objects. Metal artifact reduces the quality of image for diagnosis, so there is a necessity to present methods to reduce the artifact. The reasons for creation of metal artifacts are twofold: 1) Beam hardening of X-ray which is composed of individual photons with wide range of energies. 2) Low signal to noise ratio (SNR) which is an intense decrease of detected photons. Several methods have been suggested to reduce the metal artifact effects in CT images. These methods may be divided in two groups, means iterative and interpolation methods [2]. For example, Wang et al. used expectation maximization (EM) method and algebraic reconstruction technique (ART) to iteratively deblur metallic artifact [3]. A key step in their algorithm is the introduction of a projection mask and the computation of a 3D spatially-varying relaxation factor that allows compensation for beam divergence and data incompleteness. However, this approach is computationally expensive and not practical for clinical imaging. Prell et al. used 3D interpolation and a quasi-iterative method which did not produce suitable results for big metallic objects and also computational time

of this method was about 429 seconds [4]. In general, iterative methods have suitable results but they are time consuming. Other types of these methods are interpolation methods. The major task of these methods is to identify the corrupted region and exchange them with interpolated region. Most researchers in this method at first have adopted simple threshold to segment the metallic objects, next, they forward projected them into the sinogram domain, and finally interpolated the metal trace in original image sinogram. The shortcomings of interpolation method are: 1) Inaccurate segmentation of metallic objects, 2) Inaccurate interpolation of the metal traces. The threshold-base methods do not have accurate segmentation. Inaccurate segmentation induces loss of information from surrounding the metallic objects that exchange tissue CT number with wrong CT numbers. The lost tissue CT number reduces the quality of reconstructed image [4-6]. For example, Heng et al. in 2007 used linear interpolation method with mean-shift segmentation algorithm, for interpolating of metal traces. In this method, high consumed time (10 minutes) and enhancement of the quality of the improved CT scan images depended on primary parameters regulation which was limitations of this method [7]. The new method that is proposed in this research reduces some limitations of previous methods for example, decreasing the consumed processing time and increasing the quality of distorted images by using segmentation and interpolation methods.
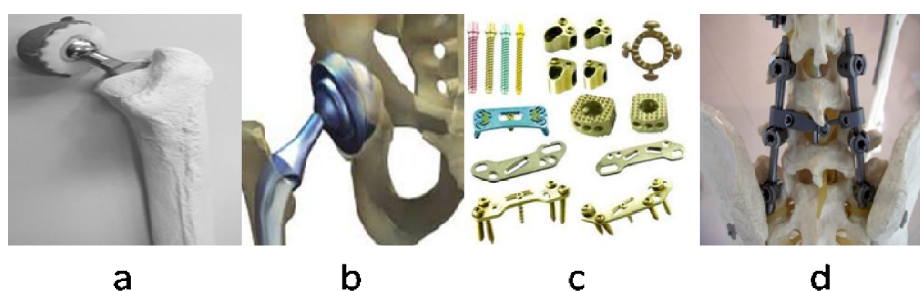

Figure 1. (a) The structure of hip implants [9], (b) How to install hip implant [9], (c) Spinal Implants [10], and (d) How to install spinal implant [11].
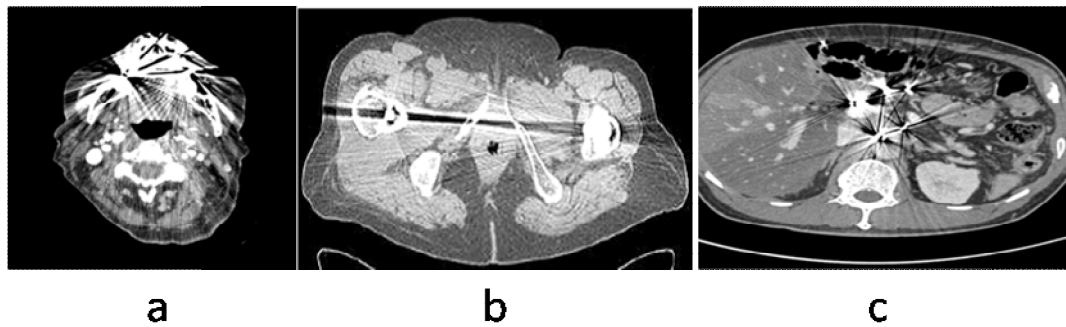
Figure 2. (a) CT image of dental implant, (b) CT image of hip implant, and (c) CT image of surgical clip in stomach region
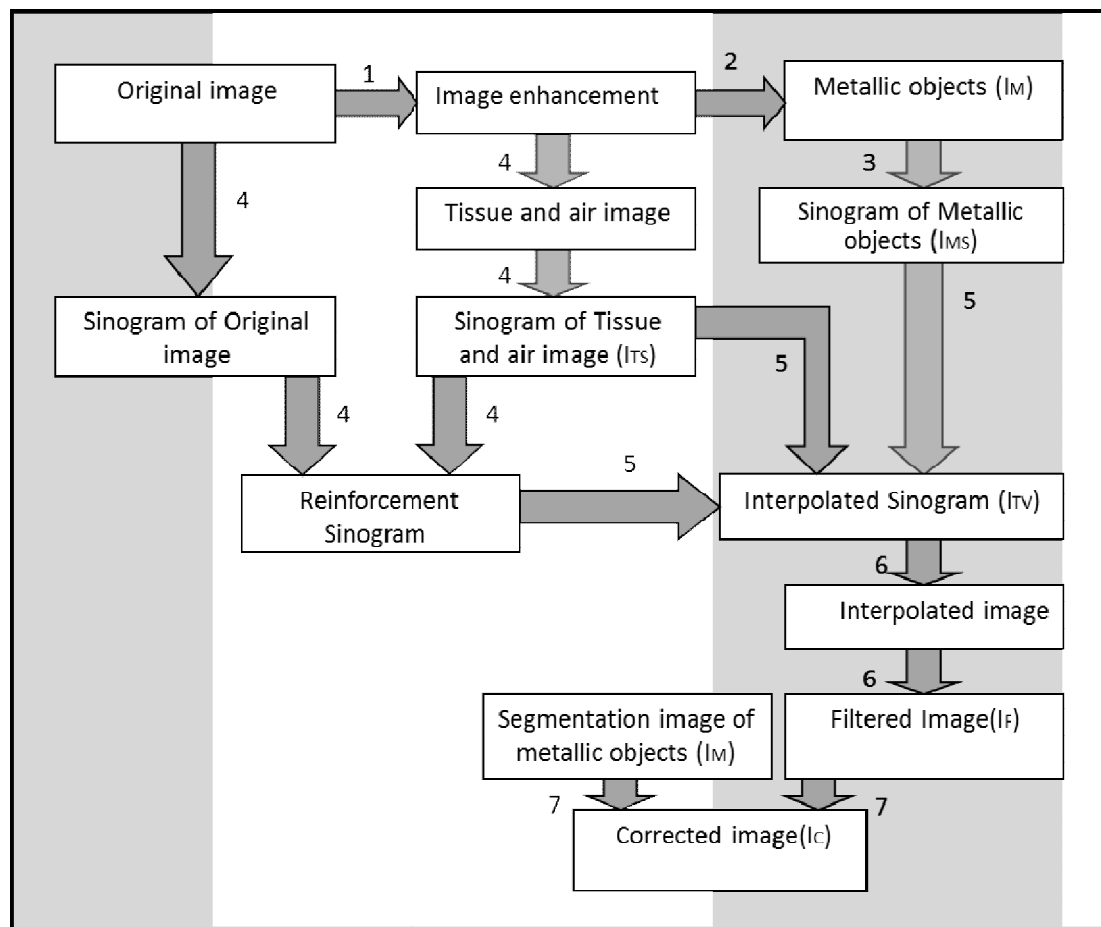

Figure 3. Flowchart of proposed algorithm

2. Materials and Methods

In this section, the implementation steps of the proposed method for suppressing metal artifact are introduced. As shown in Figure 3 the new proposed method has these steps:

2.1. Increasing image quality

Quality of images based on histogram increased in order to improve metal segmentation. In this section, at first,

undesirable regions were detected with statically methods then illumination of undesirable regions was corrected by histogram matching. This process decreased the detail of other tissues and metal artifact for metal segmentation [8].

2.2. Extracting metallic object region

The high gray level region of metallic objects was extracted automatically from original

image in order to make better metallic object segmentation and decrease the consumed time of segmentation.

2.3. Metallic objects segmentation

This research used fuzzy c- means (FCM) method for metallic objects segmentation, because of the appropriateness of the quality of FCM method. In Figure 3 I_M determined the metallic object that was segmented by FCM method. FCM method's formula is shown in (1):

$$\min_{(U,V)} \left\{ J_m(U,V) = \sum_{i=1}^{c} \sum_{k=1}^{n} u_{ik}^m D_{ik}^2 \right\} \quad (1)$$

In this formula, C is the number of clusters, V is center of each clusters, and n determine the number of pixels. U_{ik} in this formula determines dependability of pixel (i) into cluster (k). Summation of the range of dependability of each pixels to all of clusters are equal unity, therefore, the range of dependability of each pixels into clusters and also clusters center are calculable, as it is shown below [9]:

$$u_{ik} = \left[\sum_{j=1}^{c} \left(\frac{D_{ik}}{D_{jk}} \right)^{\frac{2}{m-1}} \right]^{-1}, \forall i,k \quad (2)$$

$$\mathbf{v}_i = \left(\sum_{k=1}^{n} u_{ik}^m \mathbf{x}_k \middle/ \sum_{k=1}^{n} u_{ik}^m \right), \forall i \quad (3)$$

$$D_{ik}^2 = \left\| \mathbf{x}_k - \mathbf{v}_i \right\|_{\mathbf{A}}^2 \quad (4)$$

2.4. Forward projection of original and metal image

In this section, metallic objects image and original image were transferred to sinogram domain with radon transform and named I_{MS} and I_M, respectively [8].

2.5. Sinogram correction

The best method for interpolation is to calculate CT number of metallic objects without affecting tissue CT number. To achieve this, the information of tissue in sinogram region must be reinforced, so at

first, the tissue and air region should be segmented (binary image) and next, the segmented image transferred into sinogram domain (I_{TS}). Then, the sinogram of original image should be divided to tissue sinogram and finally, the reinforced sinogram applied to metal trace interpolation.

2.6. Total Variation interpolation

In this step, the metal trace in reinforced sinogram was interpolated with Total Variation method, so, the corrected interpolated sinogram was resulted by multiplying interpolated sinogram by tissue sinogram [12].

2.7. Radon transform and smoothing

In this section, the interpolated metal traces (I_{TV}) were transferred into image domain, then remaining star traces were suppressed by use of bilateral filter and tissue edge was protected from distorting. Bilateral filter as shown in formula (5) has two parts.

$$I_F(x) = \frac{1}{K} \sum_{y=x-N}^{x+N} e^{-(I(y)-I(x))^2/2\sigma_r^2} e^{-\|y-x\|^2/2\sigma_d^2} I(y)$$

$$(5)$$

The $e^{-(I(y)-I(x))^2/2\sigma_r^2}$ is Gaussian filter used for eliminating reminder of metal artifact, $e^{-\|y-x\|^2/2\sigma_d^2}$ in bilateral formula used for protecting important edges in interpolated image (I_F) [13].

2.8. Composed background and implant images

I_F and I_M images composed by scale schema as formula (6). η is scale factor that determines the contrast of corrected image. If η =1, the contrast of corrected image is similar to the original image and if η <1, metallic objects have higher contrast in the corrected image.

$$I_C = \eta \times I_F + I_M \qquad (0.5 \leq \eta \leq 1)$$

$$I_F = \text{Filtered image}$$
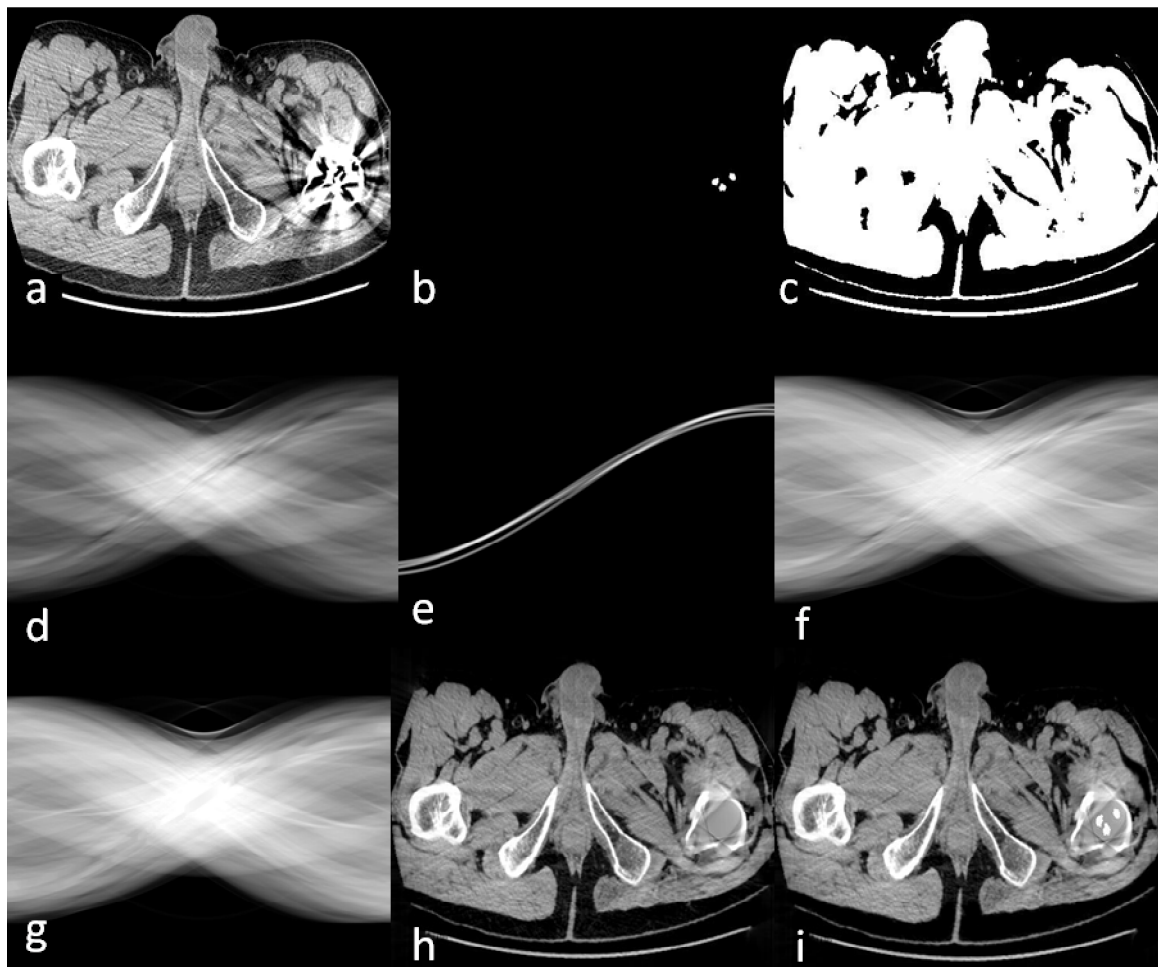$$I_M = \text{Metal image}$$
$$I_C = \text{Corrected image}$$

$$(6)$$

Figure 4. (a) Distorted hip CT image by metal artifact, (b) Segmented metallic objects, (c) The binary image of tissue and air part which is the result of FCM method in two clusters, (d) The sinogram of Figure 4.a, (e) The sinogram of metallic objects, (f) Reinforcement of sinogram (g) Interpolated sinogram (h) Filtered and interpolated image, and (i) Corrected image by proposed method.

3. Results

Fifty CT images from Alzahra hospital in Isfahan were used to evaluate the proposed method. These images included different parts of body's implant such as aneurysm, surgical clips, and hip implants. Different sizes, shapes, and places of these implants can properly evaluate the quality and consumed time of proposed method. In this section, the process steps of proposed method are shown in Figure 4. Figure 4.a shows the CT image of hip place that is distorted by metal artifact. Metallic objects in CT image (Figure 4.a) are segmented by FCM and threshold method as shown in Figure 4.b. Figure 4.c is the binary image of tissue and air part which is the result of FCM method in two clusters. Figure 4.d and Figure 4.e are

the sinogram of metal object and original images, respectively. For improving the interpolation, original sinogram are divided by tissue and air sinogram (Figure 4.f). The result of interpolated metal traces is shown in Figure 4.g. The interpolated and filtered images are shown in Figure 4.h and finally the corrected image composing of metallic objects image and corrected background image is shown in Figure 4.i. The consumed time of proposed method for correcting the hip CT image with 512×512 pixels size dimensions is 157s, which is 20% less than other methods. Based on radiologist reports, the quality of corrected images (Isfahan Alzahra hospital CT scan images that are distorted with metal artifact) enhanced 90% using of new proposed method.
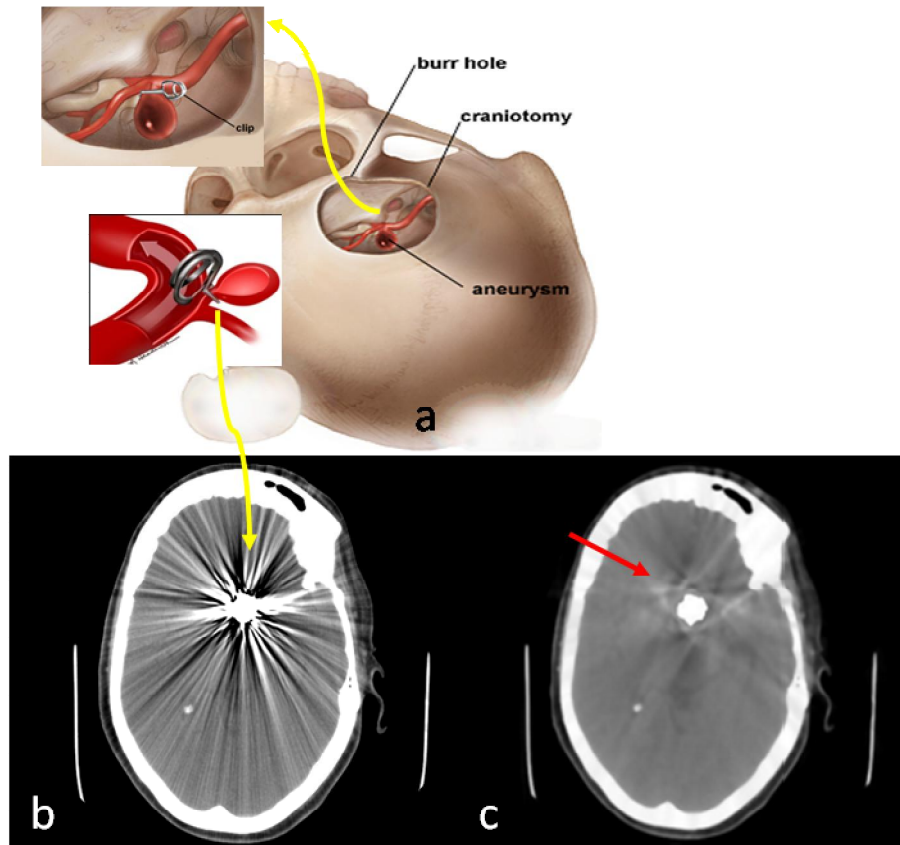
Figure 5. (a) The image of aneurysm brain and surgical clip [14], (b) Existence of surgical clip causing metal artifact, and (c) The CT image correcting by proposed method.
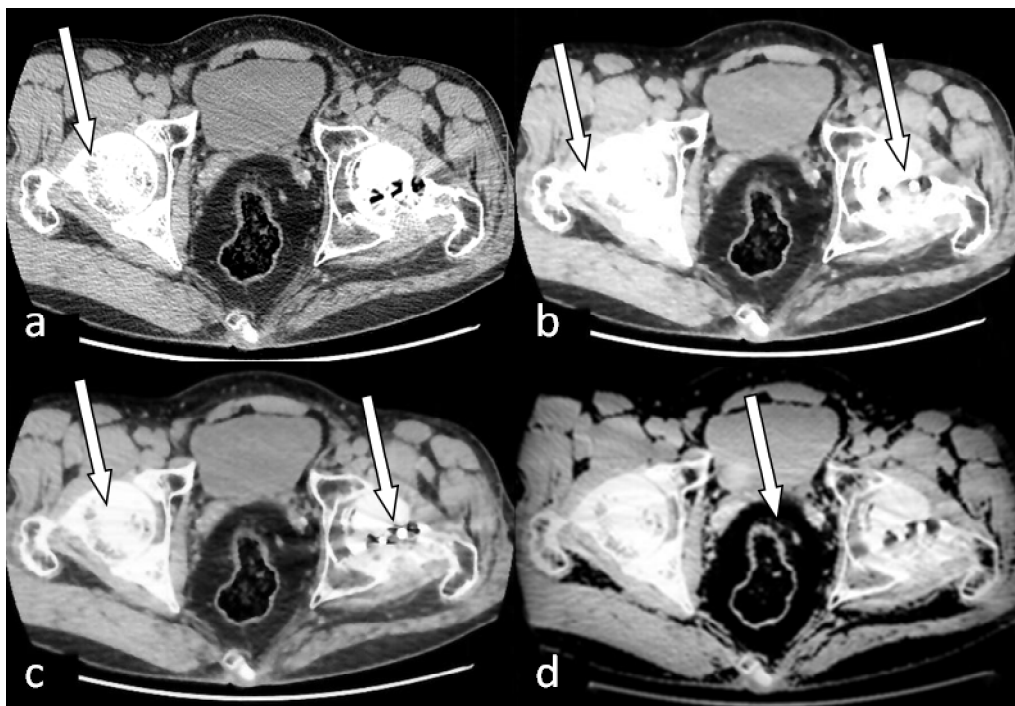

Figure 6.(a) The hip CT image that distorted by two metallic objects, (b) The corrected image by interpolated method, (c) The corrected image by TV method, and (d) The corrected image by proposed method.
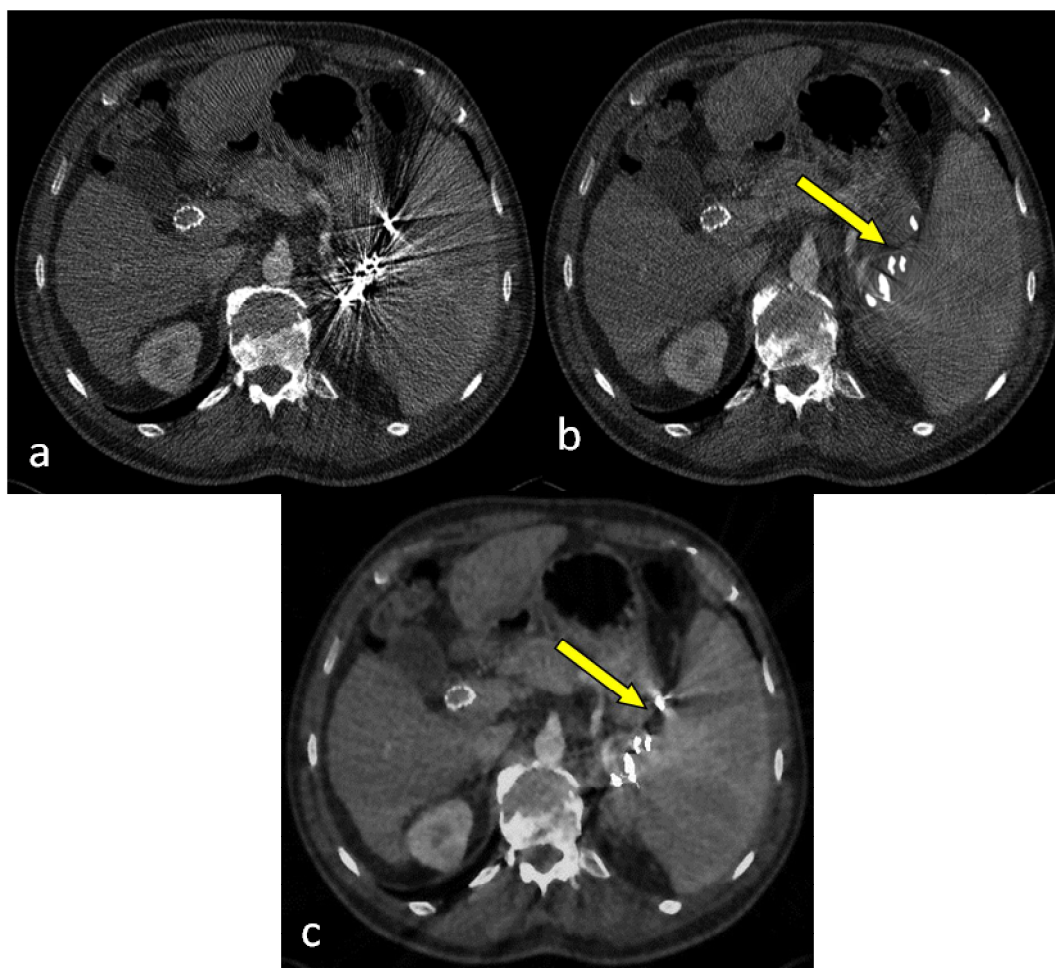
Figure 7. (a) Existence of surgical clip causing metal artifact in CT image of the stomach tissue, (b) The corrected image by metallic objects deletion method [14], and (c) The corrected image by the proposed method.

4. Discussion

In this section, the results of implementation of proposed method are described and compared with other methods. Metal artifacts cause problems in diagnosing different diseases such as aneurysm, colon cancer, and hip diseases. For example, presence of metal artifact in head region causes faulty diagnosis of brain and aneurysm diseases. In Figure 5.a, a surgical clip is displayed in brain aneurysm region. It can be observed from Fig 5.b that the existence of surgical clip causes metal artifact. Figure 5.c shows the result of implementation of the proposed method which suppressed metal artifact of Figure 5.b. After correcting the distorted image, precise diagnosis of the place of the brain aneurysm (highlighted by red arrow) is possible while before the correction it was not possible.

Figure 6 compared several methods with the proposed method. For example, we implemented the linear interpolation [7] method (introduce by Kalender et al.) on hip CT image of Alzahra hospital (Figure 6.b). Additionally, the results of total variation method [15] that was introduced by Xue et al. in 2009 is shown in Figure 6.c. The result of implementation of the proposed method is depicted in Figure 6.d. By comparison Figure 6.b with Figure 6.d, it is clear that in Figure 6.b some parts of tissue are missed and some noises are added to corrected image (shown by white arrow). By comparing Figure 6.d with Figures 6.b and 6.c it is observed that the results of Total Variation method have an advantage over linear interpolation method but both methods have some drawbacks. Proposed method suppressed disadvantages of two previous methods.

Furthermore, Figure 7 illustrates the results of Boas iterative method [16] and proposed method to suppress metal artifact from surrounding of surgical clips of stomach tissue. As shown in Figure 7 the result of proposed method on CT scan images is more successful than iterative method. Moreover, consumed time of the proposed method is less than the iterative method (about 200 seconds).

5. Conclusion
In terms of radiologists report, the outcome of the proposed methods is obviously better than previous methods in all studied cases. Additionally, consumed time of the proposed method is 20% less than previous methods. In brief, the proposed method in comparison

with previous methods used for suppressing metal artifact such as linear interpolation, Total Variation interpolation, and iterative method is more successful and advantageous, for instance it increases image quality, has suitable contrast and suitable performance for reducing metal artifact from wide spectrum metallic objects, and reduces consumed time.

Acknowledgment

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