Metal Artifact Reduction from CT Images Using Complementary MR Images

Andras A. Anderla[1], Dubravko R. Culibrk[2], Gaspar Delso[3]

Abstract – **For decades computed tomography (CT) images are widely used for receiving valuable anatomical information. Metallic implants, such as dental fillings cause severe streaking artifacts which significantly degrade the quality of images. In this paper we propose a new method for metal artifact reduction. This method utilizes possibilities which arise from using tri-modality systems.**

Keywords – **X-ray CT, metal artifacts, metal artifacts reduction.**

I. Introduction

Tri-modality systems are capable of acquiring computed tomography (CT), positron emission tomography (PET) and magnetic resonance (MR) datasets in a single session. This offers new possibilities to use the advantages of all three scanners. One of them is the reduction of metal artifacts in CT images using complementary MR images.

Metallic implants in the patient's body cause dark and bright streaking artifacts because of the high atomic number of metal. Low energy X-ray photons passing through these objects are highly attenuated and this leads to loss of projection data. In the literature different physical phenomena are reported which lead to CT images affected by the artifacts. Some of them are beam hardening, noise, Compton scattering, partial volume effect, cardiac and respiratory motion [1, 2].

Metal objects are removed from the patient if it is possible, but most often in medical practice this is not the case, therefore numerous techniques are proposed for elimination or reduction of the effects caused by metallic objects. These approaches can be divided into two groups: implicit and explicit methods. Implicit methods try to suppress artifacts without the need to apply algorithmic mathematical methods for metal correction. Their drawback is that they have limited applicability. On the other hand, explicit methods have more general approaches and they represent the main focus of researchers. An extensive list of existing techniques and methods can be found in this paper [3].

According to the authors, explicit techniques can be grouped into three categories: corrections in the sonogram domain, corrections in the image domain and iterative reconstruction algorithms.

Corrections in the sinogram domain further can be divided into interpolation-based and noninterpolation-based sinogram correction techniques. Some of the interpolation-based algorithms are described in [4, 5, 6]. The basic idea consists in finding projection bins which are influenced by the metal in the raw data and then replacing them with values calculated with linear interpolation method. The affected projection bins are usually found with simple thresholding techniques. After the correction performed in the sinogram domain, data is backprojected in order to reconstruct the image. Noniterpolation-based algorithms instead of interpolation use different approaches, such as Monte Carlo simulation [7], or bilateral filter [8]. Methods in the sinogram domain generally give better results than other methods, but on the other hand, working with raw data is often cumbersome because of their large size and the need to account for proprietary data formats and specific system geometries.

Corrections in the image domain deal with reconstructed images. Kennedy *et al* [9] proposed a method which uses a Bayes classifier, high and low threshold to detect bright and dark artifacts. Another approach is described in [10], where the authors used a dental cast model to replace regions affected with artifacts. The drawback of these methods is that affected pixel values most often are replaced with constant values which further leads to degradation of the visual image quality. However, working with reconstructed images is faster and more generic, as it can be applied across different acquisition systems.

Iterative reconstruction algorithms include algebraic and statistical techniques. Some of proposed methods can be found in [11, 12, 13]. Iterative reconstruction is carried out after the detection of affected projection bins. These methods require high computational time.

Beside mentioned techniques, several hybrid techniques also exist which try to combine different methods. Nuyts and Stroobants proposed a method which is a combination of linear interpolation and iterative reconstruction [14]. Another hybrid approach is presented by Tuy, where the author used a combination of interpolation and noninterpolation-based sinogram correction [15].

All of the methods presented above have the same limitation – they all use only data available from CT. Since metal objects create regions with missing projection data, their results strongly depend on the size and number of metal implants present in the patient's body. Recent availability of tri-modality systems gives an opportunity to use complementary MR data for reduction of artifacts in CT images. This area is not explored yet and one of the first efforts in this field is presented in [16]. In this paper we

[1]Andras A. Anderla is with the Faculty of Technical Sciences, University of Novi Sad, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, E-mail: andras@uns.ac.rs

[2]Dubravko R. Culibrk is with the Faculty of Technical Sciences, University of Novi Sad, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, E-mail: dculibrk@uns.ac.rs

[3]Gaspar Delso is with the Department of Medical Imaging, University Hospital, Raemistrasse 100, 8091 Zurich, Switzerland, E-mail: gaspar.delso@usz.ch

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propose a new method for reduction of metal artifacts in CT images using additional information obtained from MR data. We developed a fully automatic method which detects metal implants and reduces streaking artifacts.

II. EQUIPMENT AND METHODS

Our algorithm is tested on data from two patients who were referred for a PET/CT scan and volunteered for additional MR scan. Before PET scan, the patients had a resting period after the injection of 18F-FDG. During that period MR scan was performed. All clinical procedures were approved by the local ethics committee.

In the present study we did not increase the dose of ionizing radiation to which the patients were exposed in the course of their prescribed medical treatment. Concerning MR scanning, since these scanners use magnetic and radio waves (instead of radiation) to produce images, there was no additional radiation for the patients.

The tri-modality system consists of GE Healthcare Discovery 690 PET/CT and Discovery 750w MR scanner. The MR is located in a room next to PET/CT scanner. The MR table in undockable and it was moved with a shuttle device (Innovation Design Center, Thalwil, Switzerland) to the PET/CT room. With this possibility the patient did not have to alter his position.

The PET/CT acquisition followed the standard clinical protocol for an oncological whole-body study (helical CT scan, 120 kV, 20–100 mA with auto-mA intensity modulation, convolution kernel 'GE-Standard' (low-pass), 512 × 512 matrix, 0.98 × 0.98 × 3.27 mm^3, 2 min PET stations, ~300 MBq FDG).

The MR sequence was a LAVA-Flex, a 3D fast spoiled gradient echo sequence. It is a two-point Dixon method that provides four separate contrasts (water, fat, in-phase and out-of-phase) in one single acquisition. This sequence in routinely used on all whole-body tri-modality patients to provide T1-weighted whole-body images for anatomical localization.

The Integrated Registration tool which is available at the GE Advantage Workstation was used to verify the proper alignment of the different datasets.

Our method can be separated in two parts: detection of metal artifacts and correction algorithm.

The detection of artifacts in the image is achieved using Otsu's thresholding method [17]. This approach is based on an idea which is finding the threshold that minimizes the weighted within-class variance and operates directly on the gray level histogram. Basically, the image is divided into n classes. As the number of classes increases, selected thresholds become less valid. Experimenting with images with artifacts, we found that 50 classes is an optimal choice for metal region identification. Fig 1. shows the result after setting the number of classes to n=50. As it can be seen, the original CT image contains severe dental artifacts with streaking lines. After the Otsu's thresholding method is applied, obtained mask shows that the streaking lines are detected along with dental implants.

Once the artifact regions are identified, we use the correction algorithm to modify pixel values and thus reduce the effects of present metal objects. The algorithm proposed in this paper changes the values of corrupted pixels and uncorrupted pixels are left undisturbed. Corrupted pixels are the white pixels on the threshold mask.

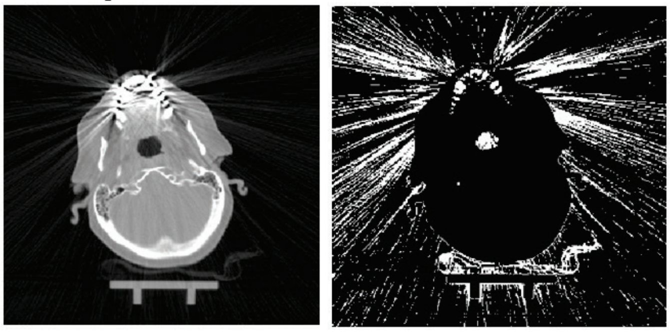

Fig. 1. Axial view of a patient showing artifacts in the CT (left) and corresponding threshold mask (right)

CT images have 512 x 512 gray scale pixel resolution. The proposed method consists of the following steps:

Step 1: A two dimensional 5 x 5 window is slid over the CT image. Experimenting with different window sizes, it is determined that 5 x 5 is the optimal size. Larger window sizes significantly reduce the speed of the correction method, and the final results do not show better visual quality.

Step 2: If the central pixel is a corrupted pixel, then its value is changed according to the next step. Otherwise, it is considered uncorrupted and the window is slid to the next position.

Step 3: We find the same pixel position on the corresponding MR image and then look for the position of most similar pixel value to the central pixel value in the 5 x 5 window.

Step 4: We look at the CT image pixel with the same position as newly found MR pixel position. If that pixel is uncorrupted in CT, then its value is assigned to the central corrupted pixel in CT. In case that pixel is also corrupted in CT, we look at the next most similar pixel in MR image and repeat this step until we find an uncorrupted pixel.

The following algorithm is based on the method described above:

if $CT_{x,y}$ *= corrupted*
    determine pixel value at $MR_{x,y}$
    find $MR_{x+k,y+k}$ *most similar to* $MR_{x,y}$
    if $CT_{x+k,y+k} \neq$ *corrupted*
        $CT_{x,y} = CT_{x+k,y+k}$
    else
        find next $MR_{x+k,y+k}$ *most similar to* $MR_{x,y}$
    end
else
    move to next $CT_{x,y}$
end

where $CT_{x,y}$ and $MR_{x,y}$ are pixel values at location x, y and $CT_{x+k,y+k}$ and $MR_{x+k,y+k}$ are pixel values within 5 x 5 window where x, y are in the center of the window. This indicates that values for k are in range from -2 to +2.

Fig. 2 shows thresholding mask applied on the CT image with artifacts and corresponding MR image, respectively.

These two images were used as an input in the proposed algorithm which has been implemented in Matlab.

Since the algorithm cannot be applied to border pixels, the first two and the last two columns are replicated at the front and rear end of the CT image, respectively. Similarly, the first two and the last two rows are replicated at the top and bottom of the CT image, respectively.

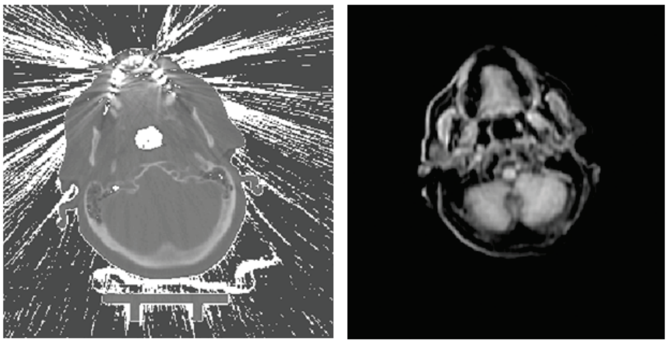

Fig. 2. Thresholding mask on CT image and corresponding MR image

III. RESULTS AND DISCUSSION

The results of the proposed method are shown in Fig. 3. The resulting images do not have secondary artifacts, which is very often an issue with other image based artifact reduction methods. It can be observed that our method is particularly effective in reducing streaking lines in the area outside the skull, so it is suitable for creation of PET attenuation maps.

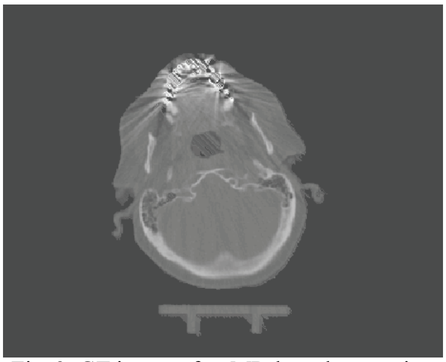

Fig. 3. CT image after MR-based correction

CT images are commonly used for attenuation maps for correcting PET data and therefore it is important to provide CT images with artifacts reduced as much as possible. MR – based attenuation correction is not as straightforward as CT attenuation correction which allows the estimation of 511 keV attenuation maps from CT images. However, there are some studies which try to utilize MR-based attenuation correction [18, 19]. The most difficult task in creating attenuation maps from MR images is the discrimination of bone tissue. This is an object of current research.

A study conducted on 152 patients [16] showed that most of patients (80%) had dental fillings. That is the reason why we primarily focused on dental implants. Nevertheless our approach could also be applied in cases other than dental fillings, such as subclavian ports or hip implants.

However, this method also presents some weaknesses. The achieved improvement is limited by bone tissue extraction. It is a common problem to isolate the bone tissue from thresholding. Since bone structures have high density, they appear bright on CT images and it is hard to separate them from metal implants which often occur in their vicinity. MR images could help to overcome this problem. One possible solution is to use fast MR sequences which are capable of detecting bone tissues and in that case MR images could be used to isolate high density structures other than metal.

In order to test the robustness and practical applicability of proposed method a larger population of patients is required. Considering that, we could also examine how the position, size and number of metal objects influence on the results.

In the context of this research study we were taking clinically indicated PET/CT patients and they were asked to volunteer for the additional MR, at no expense on their part. In the future, the tri-modality setup is expected to be used as a one-stop-shop for patients that would require both PET/CT and MR information in the course of their treatment. This would combine the clinical benefit of having spatially and temporally matching datasets, as well as the economical benefit of reducing the costs of running separate imaging centers and having the patient attend separate imaging systems.

IV. CONCLUSION

In this paper we proposed a new method for metal artifact reduction. What is novel is that we used a combination of Otsu's thresholding method along with paired MR images.

The method has been shown to be effective in eliminating streaking artifacts that originate from metal. Our approach is fast and simple and it is fully automated. There is no need for manual interaction for defining the region of interest.

Another benefit is that there is no need to work on complex raw CT data. It should be noticed that currently this method is limited to a number of clinical centers which have available tri-modality systems.

Further research will be focused on soft tissue reconstruction and on a larger population of patients. Also, working in the sinogram domain instead of image domain should improve our results which could open the way in using this method in everyday clinical practice.

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