Edge–Preserving Metal Artifact Reduction in Computed Tomography

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Purpose:

Metal implants lead to severe artifacts in CT images and degrade their diagnostic value. Many approaches for metal artifact reduction (MAR) are based on the assumption that data from the metal–affected parts of the rawdata (the metal trace) are unreliable and replace them completely by inpainting [1, 2, 3]. Our new algorithm, frequency split metal artifact reduction (FSMAR) additionally uses a frequency split approach, which was used in CT for other purposes than MAR in references [4,5]. It ensures high image quality and details with sharp edges even close to implants.

NMAR Algorithm:

In this work, FSMAR is combined with NMAR, an inpainting–based MAR method which introduces less new artifacts by using a normalization scheme before the inpainting step [6]. A diagram of NMAR is shown in figure 1. After segmenting a metal image and computing metal sinogram by forward projection, a prior image is computed by segmenting soft tissue and bone. The original sinogram is then divided pixel–wise by the sinogram of the prior image. Subsequently, the metal trace in these normalized projections is replaced by linear interpolation. The sinogram is denormalized and reconstructed.

FSMAR Algorithm:

Figure 2 provides a diagram of the FSMAR algorithm. The first step is to reconstruct an uncorrected image f^{Orig}. Subsequently, a metal image and metal projections are obtained as described above. Subsequently, an image f^{MAR} is computed by an inpainting–based MAR method, for example NMAR. Afterwards, FSMAR requires only the image–based filtering of three volumes, and two additions and multiplications of the resulting volumes. Thus, FSMAR is computationally very efficient compared to iterative MAR methods. The FSMAR image f^{FSMAR} is the sum of a low–pass filtered version of f^{MAR}, denoted as f^{MARlo} and a weighted sum of the high frequencies of the uncorrected image and f^{MAR} (denoted as f^{Orighi} and f^{MARhi}). The low–pass filtered images are computed here by a convolution with a Gaussian G:

$$f^{\text{MARlo}} = f^{\text{MAR}} * G,\quad f^{\text{Origlo}} = f^{\text{Orig}} * G$$

The corresponding high frequencies are the difference between an image and its low–pass filtered version:

$$f^{\text{MARhi}} = f^{\text{MAR}} - f^{\text{MARlo}},\quad f^{\text{Orighi}} = f^{\text{Orig}} - f^{\text{Origlo}}$$

The high–frequency part of the uncorrected image contains important edge information close to the metal implants as well as the noise. Adding the high frequency part of the uncorrected image completely, would also increase the noise in the corrected image in regions more distant to the metal implants, even if there is no blurring due to loss of information due to replacing the metal trace. In order to avoid this, a spatially varying weight W is computed. For pixels close to implants the weight is chosen higher than for pixels further off the implants. The final result is a weighted sum:

$$f^{\text{FSMAR}} = f^{\text{MARlo}} + W f^{\text{Orighi}} + (1-W) f^{\text{MARhi}}$$

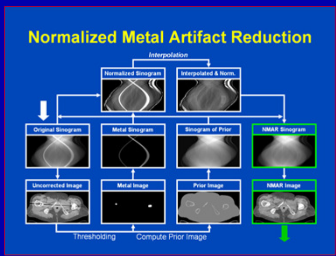

Figure 1: In the NMAR algorithm, the sinogram of a prior image is used to normalize the original sinogram before the data from the metal trace are replaced [4].

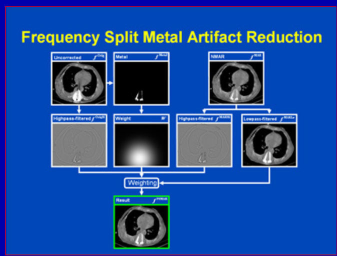

Figure 2: FSMAR uses a weighted sum of a low–passed MAR–corrected image and high–passed versions of the uncorrected image and the MAR–corrected image.

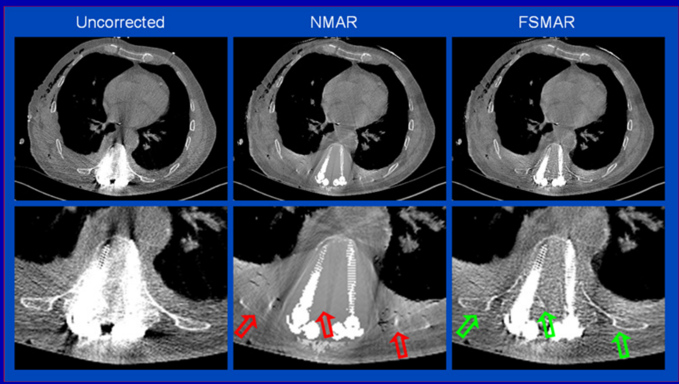

Figure 3: Patient with internal spine fixation. The NMAR result is relatively blurry in the closest vicinity of the screws. By FSMAR, the vertebra can be recovered. Between the screws there are even bone structures visible, which are not visible in the original image. (C=100 HU/W=1000 HU).

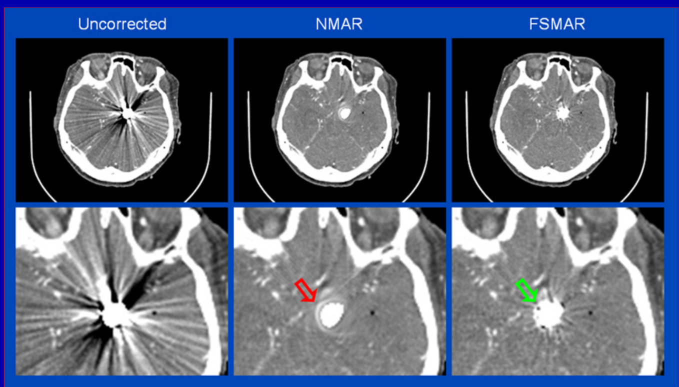

Figure 4: Patient after coiling of an intracranial aneurysm. The uncorrected image exhibits strong dark and bright streak artifacts, which make the region around the coil almost useless. A bleeding would be very hard to detect here. The artifacts are removed by NMAR. Close to the coil, slight blurring are visible after NMAR. The image with frequency split does not exhibit these artifacts. (C = 40 HU/W = 600 HU).

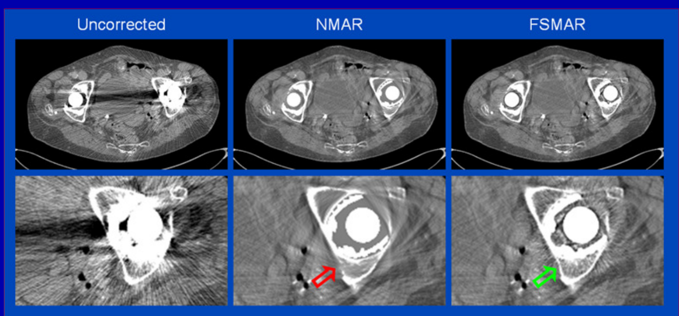

Figure 5: Patient with bilateral hip prosthesis. The uncorrected image shows dark and bright artifacts. The correction with NMAR is already quite satisfactory, but part of the bone close to the implant is blurred. The in the FSMAR result, the bone is clearly visible and has a sharp contour everywhere. (C=40 HU/W=600 HU).

Materials:

Three patient data sets with different types of implants were used to evaluate FSMAR. As the first example, a patient with internal spine fixation was used. Furthermore, a patient with a neuro coil and a patient with bilateral hip prosthesis were corrected with FSMAR.

Results:

In figures 3–5, red arrows mark the position where details are lost, green arrows mark the same position when the detail is visible.

Internal spine fixation (figure 3):

Here, large parts of the data are replaced by inpainting–based MAR methods and the NMAR result is relatively blurry close to the screws. By FSMAR, details of the vertebra are recovered even between the screws.

Coiling of an aneurysm (figure 4):

The uncorrected image exhibits strong artifacts. The artifacts are removed by NMAR, but a slight blurring is still visible, which is removed by FSMAR.

Bilateral hip prosthesis (figure 5):

The uncorrected image shows artifacts especially between the two parts of the prosthesis. The correction with NMAR is already quite satisfactory, but part of the bone close to the implant is blurred. In the FSMAR result, the bone is clearly visible and has a sharp contour everywhere.

Conclusion:

FSMAR is computationally efficient compared to iterative MAR methods and, as the results indicate, very effective. Compared to other inpainting–based MAR methods, the images do not exhibit the usual blurring close to implants. Blurry edges of bones are restored. FSMAR with NMAR is a combination which is suitable to correct both low and high frequencies in CT images with metal artifacts.

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[1] Kalender et al., Reduction of CT artifacts caused by metallic implants. Radiology, vol. 164, pp. 576–577, 1987.
[2] Mahnken et al., A new algorithm for metal artifact reduction in computed tomography: in vitro and in vivo evaluation after total hip replacement, Investigative Radiology, vol. 38, no. 12, pp. 769–775, December 2003.
[3] Veldkamp et al., Development and validation of segmentation and interpolation techniques in sinograms for metal artifact suppression in CT. Med. Phys., vol. 37, no. 2, pp. 620–628, October 2010.
[4] Shechter et al., The frequency split method for helical cone–beam reconstruction. Med. Phys., vol. 31, no. 8, pp. 2230–2236, 2004.
[5] Kudo et al., Exact and approximate algorithms for helical cone–beam CT. Phys .Med. Biol., vol. 49, no. 13, pp. 2913–2931, 2004.
[6] Meyer et al., Normalized metal artifact reduction (NMAR) in computed tomography. Med. Phys., vol. 37, no. 10, pp. 5482–5493, 2010.

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