Adaptive Normalized Metal Artifact Reduction (ANMAR) in Computed Tomography

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Purpose:

Many methods for metal artifact reduction (MAR) completely replace the metal-affected parts of the rawdata (often called the metal trace) [1, 2, 3]. However, inpainting cannot exactly recover the true values and thus the corrected images will exhibit new artifacts. Figures 1 and 2 give an overview of these methods. In reference [4], we presented the normalized metal artifact reduction (NMAR) to suppress those new artifacts. Still, this is a complete replacement scheme and leads to some loss of data.

The intersection length of rays with metal objects which have an elongated shape strongly depends on the view direction. If the mean intersection length is rather short in a projection, the corresponding part of data still contains valuable information. In this work we introduce an adaptive version of NMAR (ANMAR), which is designed to use data from the projections which are less corrupted. The merging is rawdata-based and ensures that metal artifacts are reduced, while excessive loss of data is avoided.

Materials and Methods:

A. NMAR Algorithm (details in [4])

Figure 3 provides a diagram of NMAR. First, the uncorrected image is precorrected by MAR with linear interpolation (MAR1). From this image, a prior image is computed by segmentation of 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. Then, the sinogram is denormalized. After reconstruction, the metal image is reinserted.

B. ANMAR Algorithm

Figure 4 provides a diagram of the ANMAR algorithm. The first step is to reconstruct an uncorrected image. Subsequently, the metal image is obtained by thresholding. This image is forward projected to obtain the metal projections. Then, NMAR is performed as described above. The final ANMAR-corrected sinogram is the weighted sum of the original sinogram and the NMAR-corrected sinogram. The metal sinogram has to be reinserted into the NMAR sinogram before the summation in order to produce consistent data.

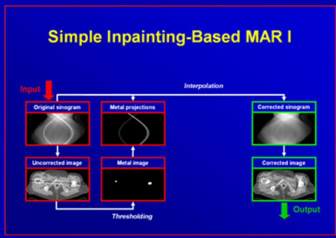


Figure 1: The data from within the metal trace are completely replaced, for example by linear interpolation in channel direction (MAR1). Reconstruction yields the corrected image.

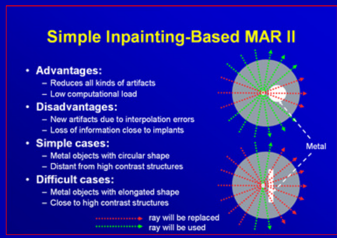


Figure 2: For objects with elongated shape, large amounts of data have to be replaced even if these data might still contain useful information in some view directions.

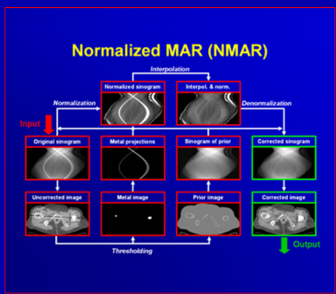


Figure 3: NMAR as described in reference [4]. A prior image is computed by segmenting bone and soft tissue regions. The sinogram of the prior image is used to normalize the original sinogram before the data from the metal trace are replaced.

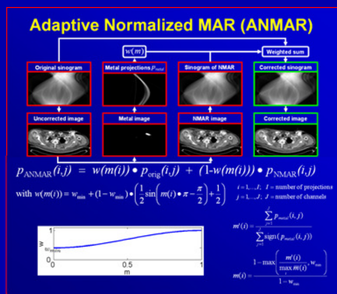
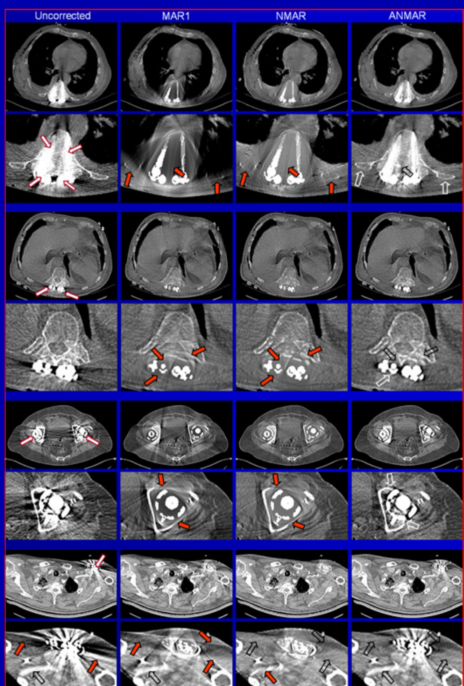


Figure 4: ANMAR is based on the idea that the corruption of the rawdata differs with the average intersection length of rays with metal. The ANMAR corrected projections are a weighted sum of original and NMAR projections. A weight is computed for each projection.

The metal projections are used to determine the weights. A weight w is computed for each projection. The weight depends on the mean value of the metal projection values from within the metal trace. The weighting function from figure 4 was used for the examples shown in this work.

C. Materials

ANMAR was tested on patient data sets with several types of implants of different shape. The first patient has a fixation of the spine with screws. Additionally, a patient with bilateral hip prosthesis and a patient with cardiac pace maker are considered.



Results for a patient with a spine fixation consisting of two metal rods parallel to the spine and screws which are fixed in the vertebrae. Shown are results for one slice with screws and one without screws. Especially in the first example, the MAR1 results exhibit new artifacts due to interpolation errors. NMAR removes the artifacts, but the details of the vertebra are still blurry. The uncorrected image exhibits dark and bright artifacts especially in the direction of the screws. The MAR1 result is rather blurry as big parts in the projection data are replaced. While NMAR removes the dark artifacts, some bone structures are not preserved. ANMAR reduces the metal artifacts, while bone structures and the spinal canal are shown very clearly. (C = 100 HU / W = 1000 HU)

Results for a patient with bilateral hip prosthesis. In the ANMAR result, in contrast to the MAR1 and NMAR results, no bone structures are blurred even directly at the metal prosthesis. Also, the image texture is very natural even in the region of the prosthesis. (C = 40 HU / W = 600 HU)

Results for a patient with cardiac pace maker. MAR1 introduces, new artifacts due to interpolation errors. NMAR removes the artifacts, but the vessel below the pacemaker is slightly blurry. In the ANMAR result the vessel is sharp while the metal artifacts are reduced. (C = -40 HU / W = 600 HU)

Figure 5: Comparison of uncorrected images and results corrected by MAR1, NMAR and ANMAR for different patient data sets. White arrows outlined in red in the left column mark metal implants. Red arrows outlined in black indicate artifacts. Arrows outlined in black or white indicate the same position in an image where there is no artifact. While the ANMAR images can still contain some remaining metal artifacts, details close to metal implants can be preserved more accurately. For each patient, one row shows the full images and one row shows a magnified part around the metal implants.

Results:

Figure 5 shows the ANMAR results as well as uncorrected images, MAR1-corrected images, and NMAR-corrected images for comparison. The uncorrected images exhibit noise and bright and dark band artifacts, especially in the directions with long intersection lengths of rays with metal. In the MAR1 results, new artifacts due to interpolation errors are introduced. NMAR removes these artifacts, but some details close to the metal implants can be blurred. ANMAR reduces the metal artifacts, while also details even in the closest vicinity of the implants are preserved.

Conclusion:

Metal artifacts drastically impair the image quality in CT images. While inpainting-based MAR methods are efficient in removing all kinds of metal artifacts, they can lead to blurring close to implants due to loss of data. In this work we introduced ANMAR, an algorithm with rawdata–based merging of original and NMAR data. ANMAR removes severe metal artifacts while it ensures that data which are not corrupted too severely are also used. Details close to and even between implants are better preserved. Additionally, ANMAR-corrected images exhibit a very natural appearance also in the region of the implants.

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[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] 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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