CT Data Completion Based on Prior Scans

Thorsten Heußer[1], Marcus Brehm[1,2], Stefan Sawall[1,2], and Marc Kachelrieß[1,2]

[1]Medical Physics in Radiology, German Cancer Research Center (DKFZ), Heidelberg, Germany

[2]Institute of Medical Physics, Friedrich-Alexander-University (FAU), Erlangen, Germany

Purpose:

This work proposes a generalized prior-based artifact correction method (PBAC) for prominent CT artifacts resulting from missing data, e.g. limited angle artifacts, metal artifacts, and truncation artifacts, by performing data completion based on prior knowledge.

The artifact-free prior data are registered to the measured patient data using a deformable registration algorithm, followed by forward projection, smooth sinogram inpainting, and image reconstruction.

Materials and Methods:

X-ray CT often suffers from artifacts due to missing data. In clinical CT for example, so-called hollow projections arise when metal objects, e.g. metal hip implants or metal pedicle screws, cannot be sufficiently penetrated by the x-rays. In flat detector CT additional artifacts originate from projection truncation, which occurs when the patient is larger than the field of measurement covered by the detector. Other artifacts result from a limited scan angle when the CT device cannot perform a full 180° rotation, for example in some interventional C-arm CT devices.

By now, each of these artifacts have often been approached using specific correction methods based on projection data extrapolation or interpolation.

However, in many cases prior data are available which can, potentially, be used to correct for the missing CT data. These prior data may be a different scan of the same patient, e.g. a planning CT, or even a patient from a patient database. We propose to use these prior data to fill the gaps in the CT data and thereby to reduce the artifacts.

In order to be able to compare the corrected images to the ground truth (GT), we chose to simulate the investigated artifacts rather than to use data containing real artifacts. We use different scans of the same patient as well as different patients as prior data to perform data completion.

To compensate for differences between acquisitions due to a changed patient positioning or between two actual patients, the prior data are co-registered with the measured patient data. We use a deformable registration method based on the demons algorithm [1].

The registered prior volume is forward projected using Joseph's algorithm [2]. Now, the gaps in the patient projection data are filled with the corresponding data of the registered prior. It should be noted that this data inpainting is done in a smooth way, ensuring a smooth transition between the measured patient data and the incorporated prior data.

The resulting composite sinogram is finally reconstructed using a 3D cone-beam filtered backprojection based on the Feldkamp algorithm [3] to obtain the corrected volume.

Results:

We evaluated the prior-based artifact correction method (PBAC) investigating three different patient datasets and using prior data from the same or a different patient.

For the metal case, the severe streak artifacts vanish almost completely while the patient-specific anatomy is preserved in contrast to the linear interpolation approach.

Truncation artifacts can be corrected for efficiently by using common data extrapolation methods. However, the corrected images obtained with PBAC show even better suppression of the cupping artifacts and additionally provide a better overall orientation of the patient anatomy.

In the limited angle case, there are still significant artifacts left after PBAC. Compared to standard correction techniques however, the results obtained with the proposed correction method show a significant improvement in artifact suppression.

Conclusion:

PBAC is a highly effective method to reduce all kinds of artifacts resulting from missing data if adequate prior data is available.

Acknowledgment:

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References:

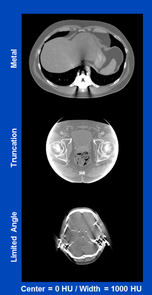
[1] M. Brehm, P. Paysan, M.Oelhafen, P. Kunz, and M. Kachelrieß. Self-adapting cyclic registration for motion-compensated cone-beam CT in image-guided radiation therapy. *Med. Phys.*, in Press.

[2] Peter M. Joseph. An improved algorithm for reprojecting rays through pixel images. *TMI*, MI–2(3):192–196, November 1982.

[3] LA Feldkamp, LC Davis, and JW Kress. Practical cone-beam algorithm. *JOSA A*, 1(6):612–619, 1984.

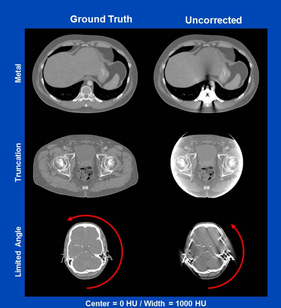
About this Work

- **Motivation**
  - CT often suffers from artifacts due to missing data
  - Many existing correction methods often struggle with completely removing these artifacts without introducing new artifacts simultaneously
- **Idea**
  - In many situations, prior data are available
    - » Planning CT
    - » Patient database (anatomic atlas)
  - Make use of these prior data to fill the gaps in the measured data
- **Aim**
  - Generalized correction method for all kinds of artifacts resulting from missing data



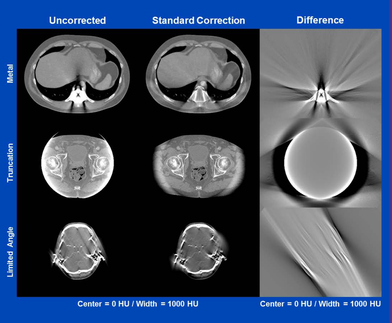
Artifacts

- **Simulate artifacts rather than using images containing measured artifacts**
  - Ground truth is always available and serves as a benchmark for the proposed prior-based correction method
- **Metal artifacts**
  - Two pedicle titanium screws
  - Calculate projection values considering polychromatic attenuation
- **Truncation artifacts**
  - Reduce size of detector such that patient is not completely covered by the field of measurement
- **Limited angle artifacts**
  - Reduce scan angle from 180°+fan angle to 120°+fan angle



Standard Corrections

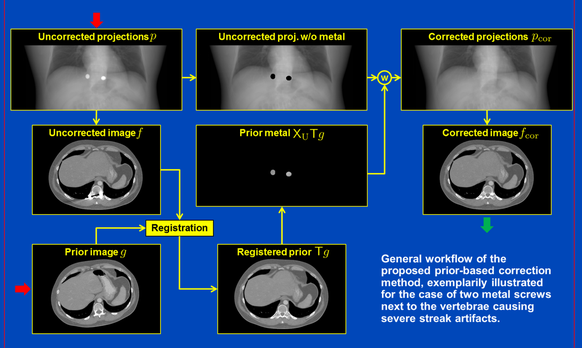
- **Standard corrections**
  - Simple data extra- or interpolation modifying the projection data
  - Specific for each type of artifact
- **Metal**
  - Linear interpolation between metal boundaries
- **Truncation**
  - Detector enlargement and cos²-extrapolation of the measured data to zero
- **Limited angle**
  - Smooth outfading of projection values in the angular direction



Prior-Based Artifact Correction (PBAC)

- **Input 1**
  - Incomplete/corrupt projection data p
- **Uncorrected image**
  - $f = \mathsf{X}^{-1}p$, where X denotes the x-ray transform and X^{-1} denotes image reconstruction
- **Identify missing data**
  - Decompose x-ray transform into measured and unmeasured rays, $\mathsf{X} = \mathsf{X}_{\mathrm{M}} + \mathsf{X}_{\mathrm{U}}$, with the latter corresponding to the data that shall be completed
  - For those rays corresponding to X_{U}, assume the entries of p to be set to zero
- **Input 2**
  - Nearly artifact-free prior image or volume g of the same or of another patient
- **Registration**
  - Register prior image g to the uncorrected image f to obtain an artifact-free image $\mathsf{T}g$
- **Forward projection**
  - Forward project $\mathsf{T}g$ along those rays missing in p, i.e. compute $\mathsf{X}_{\mathrm{U}}\mathsf{T}g$
- **Data inpainting**
  - Obtain corrected projections as $p_{\mathrm{cor}} = p + \mathsf{X}_{\mathrm{U}}\mathsf{T}g$
  - Inpainting is done in a smooth way ensuring a smooth transition between measured and unmeasured data
- **Image reconstruction**
  - Reconstruct corrected projections to obtain corrected image $f_{\mathrm{cor}} = \mathsf{X}^{-1}\left(p + \mathsf{X}_{\mathrm{U}}\mathsf{T}g\right)$

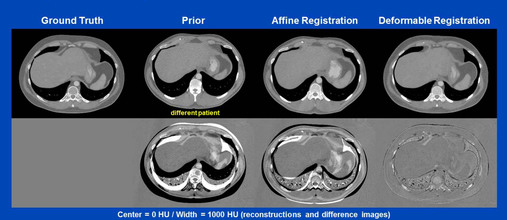
PBAC - Workflow



General workflow of the proposed prior-based correction method, exemplarily illustrated for the case of two metal screws next to the vertebrae causing severe streak artifacts.

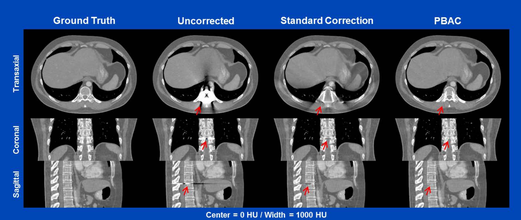
Registration

- **Compensate for differences between patient and prior**
  - due to a changed patient positioning, if the prior is a different scan of the same patient
  - between two actual patients, if the prior is a different patient
- **Affine registration**
  - Allowing for translation, rotation and scaling
- **Deformable registration**
  - More accurate than affine registration
  - Sensitive to image artifacts



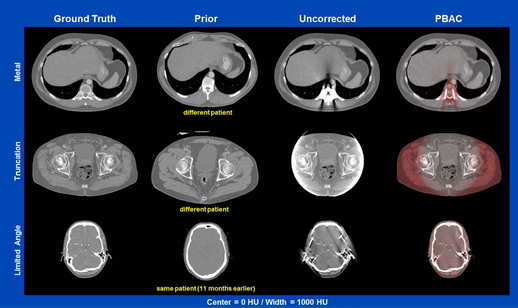
Results - MPR

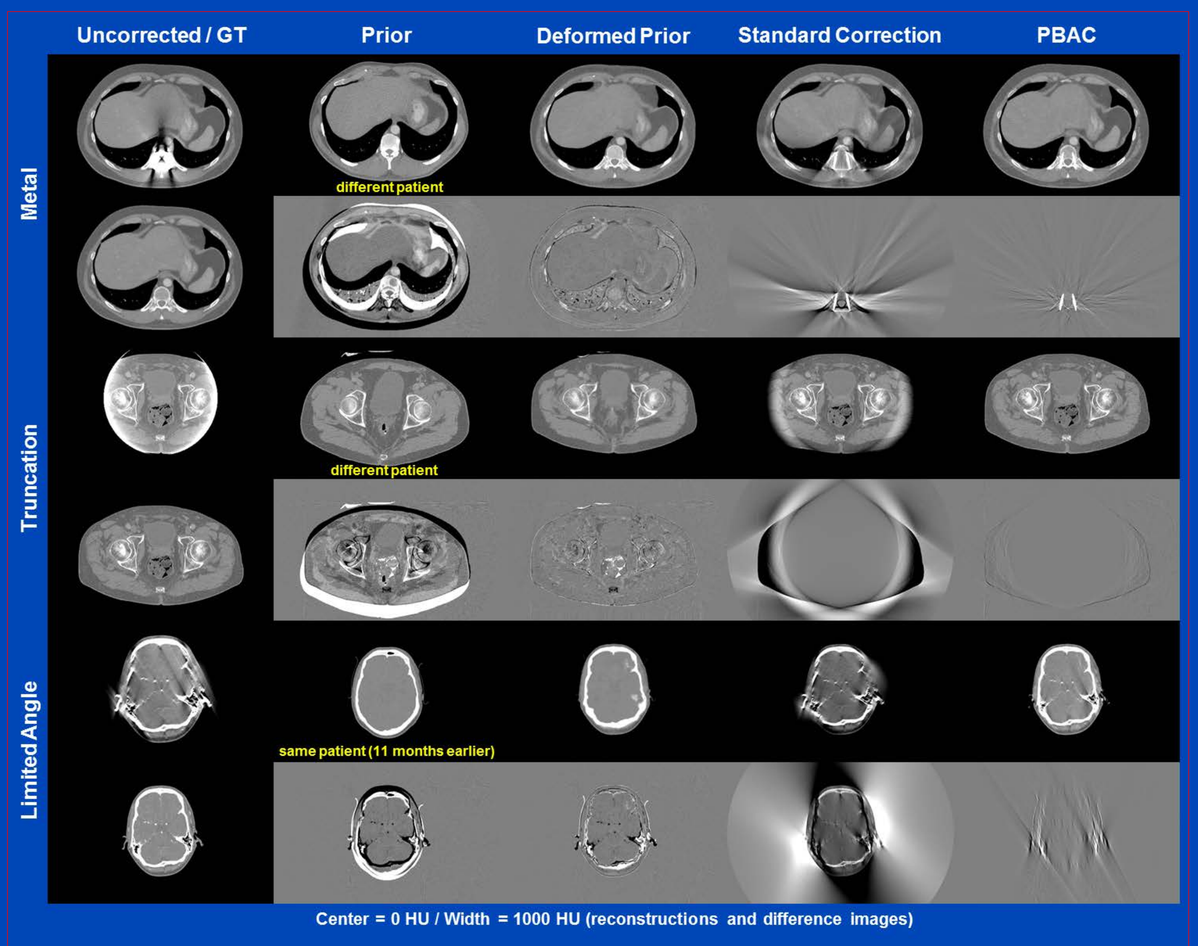
- All datasets are 3D volumes, measured at clinical spiral CT systems at the German Cancer Research Center (DKFZ), Heidelberg, Germany.
- Reconstruction is done using 3D filtered backprojection.



Influence of Prior Data

- Visualize influence of prior data on corrected image
- Redness in the PBAC images quantifies influence of prior data





Send correspondence request to:

Thorsten Heußer
thorsten.heusser@dkfz.de

X-Ray Imaging and CT (E025)
German Cancer Research Center
69120 Heidelberg, Germany

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