



White paper

HD FOV 5.0

Technical principles and phantom measurements evaluating CT number and diameter accuracy in the AI-supported extended field of view (FoV) region (SOMARIS 10/VB20)

Introduction

Accuracy of dose calculation in radiotherapy often depends on precise assignment of the electron density to each voxel in an image and precise reconstruction of patient geometry. Imaging is typically carried out on a CT simulator (CT scanner that can be used for treatment simulation and has features that support radiotherapy) with a wide-bore size (typically at least 80 cm) to accommodate bariatric cases, immobilization devices, patient positioning systems, etc. The CT simulator typically has a scan field-of-view of 50 cm – 60 cm, and in most cases the patient boundary is well within the scan field-of-view. However, in certain cases, for example, in patients with higher body mass index (BMI) or when using a positioning device such as a breast board, part of the patient's anatomy extends beyond the scan field of view. The limited data in the regions outside the scan field of view often leads to inaccurate patient geometry and often reduced accuracy of CT numbers in Hounsfield unit (HU) in the extended field-of-view (FoV) region. To overcome this, extended FoV algorithms^{1,2,3} have been developed over the years to increase the accuracy of reconstruction outside the scan field of view.

In this publication, we describe the implementation of the AI-supported extended FoV reconstruction algorithm HD FOV 5.0. Furthermore, we demonstrate CT number and geometric accuracy in the extended FoV region using phantom studies.

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Algorithm theory

The implementation of the HD FOV 5.0 algorithm consists of several steps (shown in Figure 1)

to reduce artifacts in the regions outside the scan field of view.

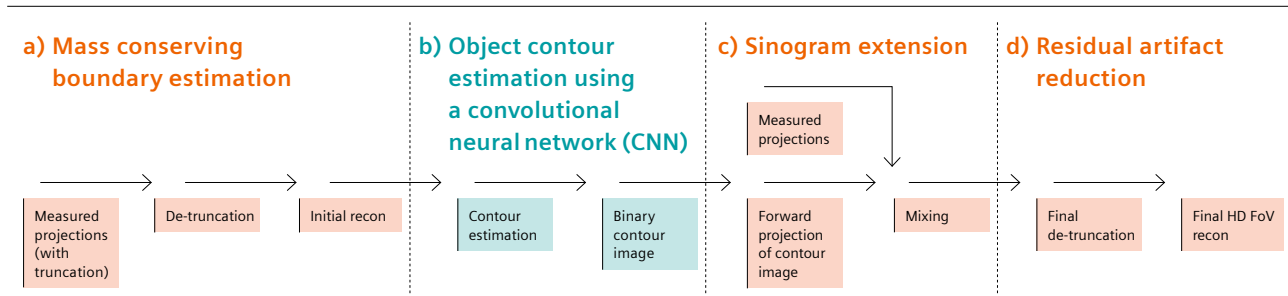


Figure 1: Algorithmic steps in the HD FOV 5.0 algorithm. All orange steps are unchanged as compared to the predecessor algorithm HD FOV.⁵ Instead of using a CT-value threshold to generate the Contour Image (HD FOV), HD FOV 5.0 uses a pre-trained convolutional neural network (CNN) to estimate the contour image from the initial reconstruction.

The HD FOV 5.0 algorithm builds up on its predecessor algorithm HD FOV⁵. While HD FOV used thresholding based on CT numbers to generate the object contour

image from the initial reconstruction, HD FOV 5.0 applies a Convolutional Neural Network for this step.

Mass conserving boundary estimation

To reconstruct information in the extended FoV region, one needs to start with an estimate of the patient boundary from the limited data available. In our implementation, we start with the assumption that every projection that covers the entire object/patient should result in a constant mass. When the object or patient body being imaged lies at least partly outside the scan field of view, this condition is violated and hence the data for those projections is truncated during measurements as seen on the left in Figure 2.

The projection mass that is defined as the normalized cumulative sum of the attenuation values of a projection varies as a function of the angle (0°–360°). As can be seen, the normalized projection mass is 1 for projection angles that see the entire patient and lower otherwise.

To de-truncate the data, a mass consistency condition is applied, and an initial estimate of the extrapolated projections is created (as seen in Figure 2). Extrapolation is carried out in projection space for the truncated projections using a cosine shaped function such that mass is consistent across all the projections. To avoid any artifacts from an abrupt transition from measured to extrapolated data, the algorithm ensures that the transition between measured and extrapolated data is smooth.

The de-truncated projections are then used to reconstruct an initial estimate of the CT image (Figure 3).

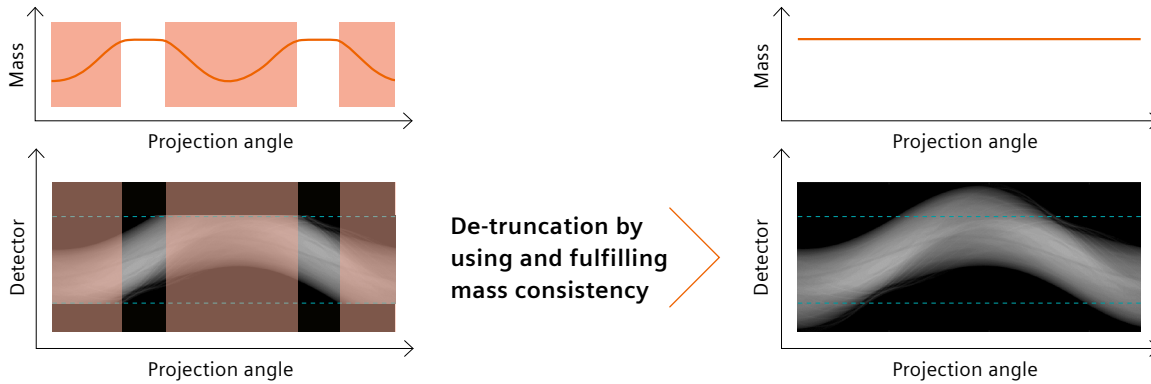


Figure 2: HD FOV 5.0 uses a data extrapolation based on the mass conservation principle to de-truncate the measured CT data.

Object contour estimation by convolutional neural network

The initial estimate of the patient that was reconstructed from the extrapolated projections in the previous step is now fed into a pre-trained convolutional neural network. In HD FOV 5.0, the convolutional neural network was realized as a UNet-like⁴ architecture and returns estimates of the full patient image – even outside the scan field of view – from the input images. The network outputs are

then transformed into a contour image by applying a CT number transformation. The characteristic curve of this transformation is shown in Figure 4. The transformation is applied to get more defined and sharper patient outlines in the contour images between air and soft tissue regions.

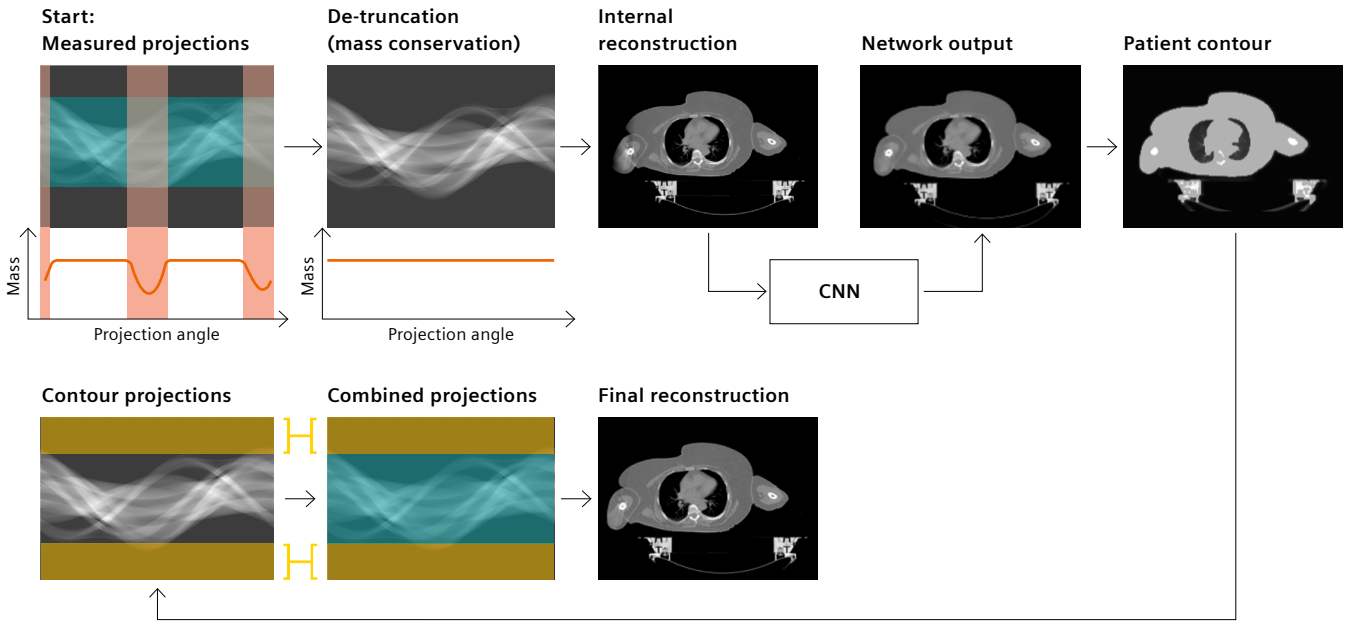


Figure 3: Flowchart of the HD FOV 5.0 algorithm. Starting with the truncated projection data an initial reconstruction is done after de-truncation. This initial reconstruction is fed into a CNN, which was trained to estimate the full object shape from input images de-truncated by mass conservation. From the network result image, a patient contour image is computed by applying a CT number transformation. The patient contour is then forward projected, and the forward projections are used to extrapolate the initial measured projection data. Note that the measured data (shaded in green color) is not altered by this extrapolation.

Forward projection of contour image and data mixing

In a last step, forward projections of the contour image are used to extrapolate the measured projection data (see Figure 1 and Figure 3). After filtering and back-projecting the mixed data, this approach can potentially result in a final image that is a close representation of the patient being imaged.

However, structures that are not covered by the contour image can still cause truncation artifacts. To remove these residual truncation artifacts a final de-truncation, i.e., a smooth fade out of the projection data towards zero, is carried out in the projection space before the final image is reconstructed.

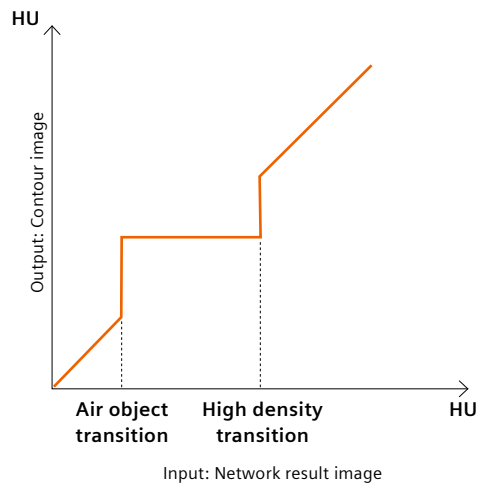


Figure 4: CT number transformation that is used in HD FOV 5.0 to generate the patient contour image from the output images of the network.

Phantom studies

To evaluate the performance of the HD FOV 5.0 algorithm we set up a study using a 33 cm diameter Gammex Electron Density phantom (Gammex, Middleton, WI, USA)⁶. The images were acquired on diagnostic 82 cm bore CT scanners SOMATOM X.cite and NAEOTOM Alpha.Prime and on an 85 cm bore CT scanner SOMATOM go.Open Pro designed for radiotherapy. The phantom was imaged at 3 different positions in the scanner as shown in Figure 5 and Figure 6.

The three positions were chosen so that for the first position the phantom was completely contained within

the scan field of view. For position two and three the height was adjusted such that parts of the phantom were located outside the scan field of view of the CT scanner. The absolute phantom positions were adjusted for the different geometries of the investigated CT scanners. Images were reconstructed using a FoV of 815 mm on the 82 cm bore CT scanners. The reconstructed FoV on the 85 cm bore CT scanners was set to 850 mm. An overview of the used phantom positions, reconstructed FoVs, and scan field of views is given in Table 1 (see also Figure 5 and Figure 6).

| CT Scanner | Position 1 | Position 2 | Position 3 | Reconstructed FoV | Scan field of view (sFoV) |
|---------------------|-------------|------------------------------|------------------------------|-------------------|---------------------------|
| SOMATOM X.cite | Within sFoV | Outer phantom edge at 630 mm | Outer phantom edge at 750 mm | 815 mm | 500 mm |
| NAEOTOM Alpha.Prime | Within sFoV | Outer phantom edge at 630 mm | Outer phantom edge at 750 mm | 815 mm | 500 mm |
| SOMATOM go.Open Pro | Within sFoV | Outer phantom edge at 740 mm | Outer phantom edge at 810 mm | 850 mm | 600 mm |

Table 1: Positions of the Gammex phantom that were used on the different scanners for the evaluation of HD FOV 5.0

Note that in case of the NAEOTOM Alpha.Prime, which is equipped with a QuantaMax photon-counting detector, the applicability of HD FOV 5.0 is limited to T3D recon-

structions which are non-spectral reconstructions that use only the data from the lower T1 threshold of the QuantaMax photon-counting detector.

CT number accuracy

CT number accuracy in the extended field of view region was evaluated by measuring the mean CT number in HU in a region-of-interest (ROI). Therefore, an ROI was placed at the 12 o'clock position within the Gammex phantom as indicated by the yellow circle in Figure 5 and Figure 6.

This measurement was repeated on 6 central slices and the average value over all slices was computed. The mean CT number within the ROI was compared to a reference mean CT number derived from the ROI in the case when the phantom is contained within the scan field of view, left image in Figure 5 and Figure 6.

Phantom diameter accuracy

Diameter accuracy was evaluated by measuring 75 line profiles distributed in equally spaced angle increments within the yellow shaded area. The angle range for the line profiles was chosen so that the whole range of truncation is approximately covered for phantom position 2, as shown by the yellow shaded region in Figure 5, Figure 6.

The full width at half maximum (FWHM) of the 75 line profiles was computed for the 6 central image slices of the reconstruction. The reported diameter is the FWHM averaged over all 75 line profiles and all slices. As for the evaluation of the CT numbers, the case where the entire phantom is contained within the scan field of view was used as reference (left image of Figure 5 and Figure 6).

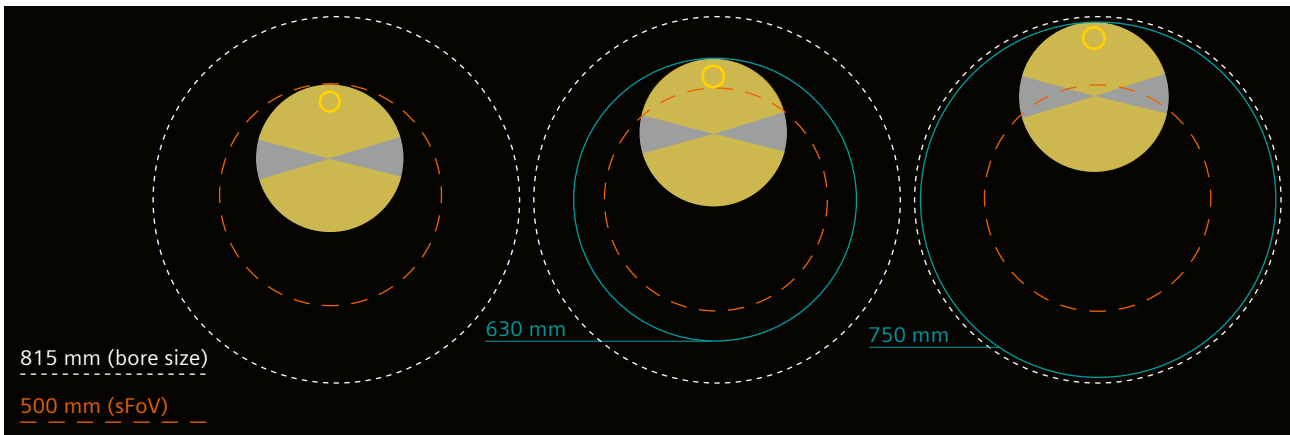


Figure 5: Measurement setup on the 82 cm bore CT scanners SOMATOM X.cite and NAEOTOM Alpha.Prime. Phantom positions were adjusted to the bore size of the scanner. 75 line profiles in the 6 central slices were used to report the accuracy of the diameter of the phantom.

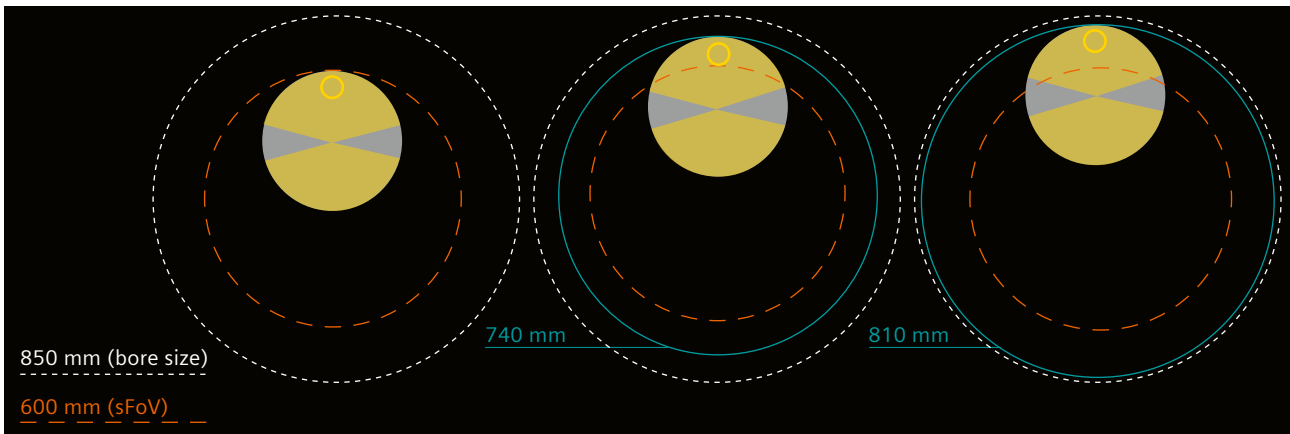


Figure 6: Measurement setup on the 85 cm bore CT scanner SOMATOM go.Open Pro. Phantom positions were adjusted to the bore size of the CT scanner. 75 line profiles in the 6 central slices were used to report the accuracy of the diameter of the phantom.

Results and discussion

CT number accuracy

Measurement of the mean CT numbers within the ROI was performed in the 6 central slices. The average of these measurements is shown in Table 2 for the different positions of the phantom: contained within scan field of view, phantom edge at position 2 (Table 1) and phantom edge at position 3 (Table 1).

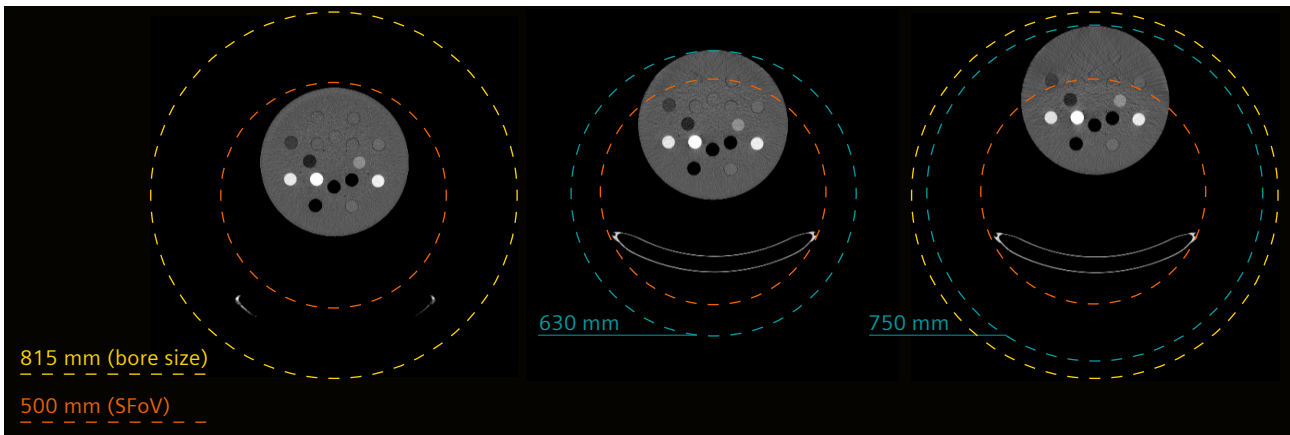


Figure 7: Results from SOMATOM X.cite. Gammex phantom reconstructed at different phantom positions (from left to right): phantom completely in the scan field of view, outer phantom edge at approximately 630 mm, and outer phantom edge at approximately 750 mm.

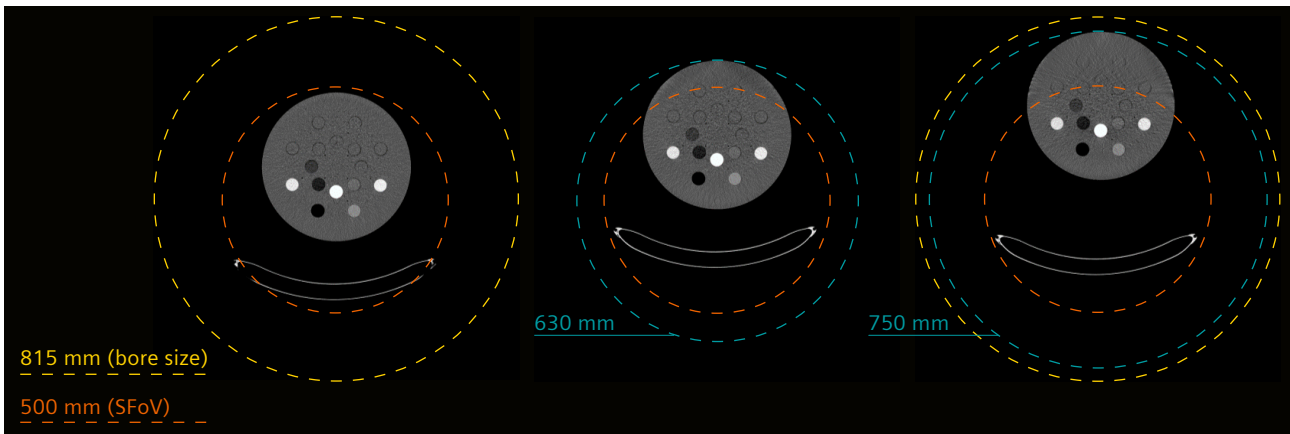


Figure 8: Results from NAEOTOM Alpha.Prime. Gammex phantom reconstructed at different phantom positions (from left to right): phantom completely in the scan field of view, outer phantom edge at approximately 630 mm, and outer phantom edge at approximately 750 mm.

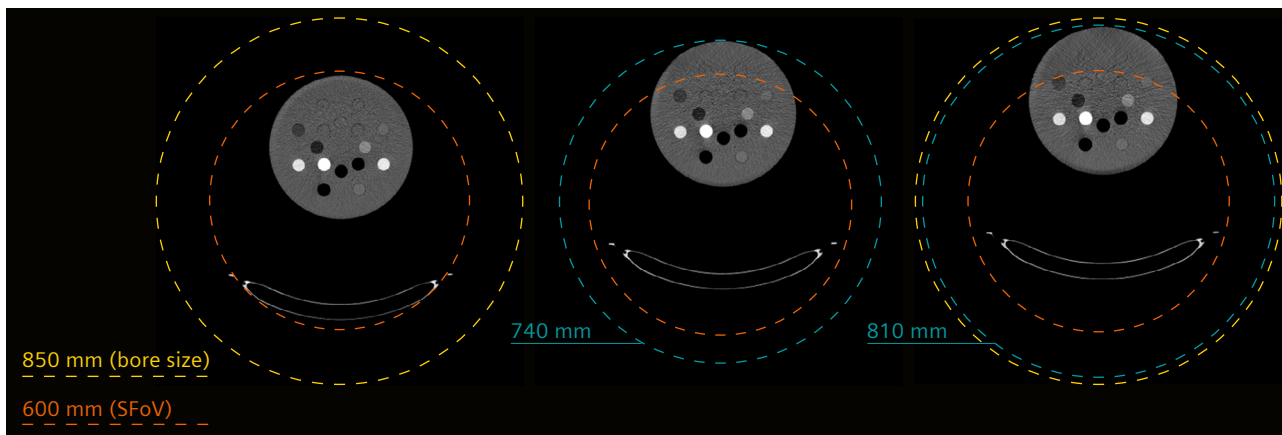


Figure 9: Results from SOMATOM go.Open Pro. Gammex phantom reconstructed at different phantom positions (from left to right): phantom completely in the scan field of view, outer phantom edge at 740 mm, and outer phantom edge at 810 mm.

| Position | SOMATOM X.cite CT number difference | NAEOTOM Alpha.Prime CT number difference | SOMATOM go.Open Pro CT number difference |
|-------------------|--|---|---|
| Position 1 (sFoV) | 0.00 HU | 0.00 HU | 0.00 HU |
| Position 2 | -1.14 HU | 1.79 HU | -2.84 HU |
| Position 3 | 1.97 HU | -3.61 HU | 1.10 HU |

Table 2: CT numbers measured in an ROI (averaged over 6 central slices) at different phantom positions: phantom completely in the scan field of view, small part of the phantom out of the sFoV, and large part of the phantom out of the scan field of view. The reported values are differences between the ROIs at different phantom positions and the reference ROI value for phantom position 1.

Phantom diameter accuracy

Mean phantom diameter was measured as the average diameter from 75 line profiles for the 6 central image slices. The case where the entire phantom contained within the scan field of view was used as reference. The results show that the accuracy of the diameter measurement is within the 3 mm range that was reported

for the predecessor algorithm HD FOV (see Table 3). The results in this phantom setup imply that HD FOV 5.0 produces a consistent phantom geometry, even in cases where large parts of the phantom lie outside the scan field of view of the CT scanner.

| Position | SOMATOM X.cite Diff. to reference diameter | NAEOTOM Alpha.Prime Diff. to reference diameter | SOMATOM go.Open Pro Diff. to reference diameter |
|-------------------|---|--|--|
| Position 1 (sFOV) | 0.00 mm | 0.00 mm | 0.00 mm |
| Position 2 | -0.13 mm | -0.30 mm | 0.42 mm |
| Position 3 | -0.09 mm | -0.29 mm | 0.93 mm |

Table 3: Mean diameter deviation of the Gammex phantom measured in central 6 slices. Difference to the reference (phantom completely within the scan field of view) is used as a metric to estimate diameter accuracy.

Summary and conclusion

We here presented and evaluated the new HD FOV 5.0 algorithm for extended field of view reconstruction, which is an evolution of the predecessor algorithm HD FOV that is available on Siemens Healthineers CT scanners. As compared to its predecessor HD FOV, the computation of the so-called Contour Image, which is an intermediate result in the algorithm pipeline, was modified with HD FOV 5.0. While HD FOV uses a CT number threshold to generate the Contour Image from the initial reconstruction, HD FOV 5.0 uses a CNN for this step.

Note that even with the usage of a trained convolutional neural network (CNN) for the computation of the internal Contour Image, the problem of extended field of view reconstruction is still strongly underdetermined and cannot be solved correctly. No matter whether we use a global CT number threshold (HD FOV) or apply a CNN

to compute the Contour Image (HD FOV 5.0), one should always be aware that the algorithm estimates data where no data was measured and therefore the image values in regions outside the scan field of view are only an educated guess of the real patient shape and CT numbers. Inside the scan field of view, all data needed for the reconstruction were measured during the scan and images resemble the patient anatomy correctly – as in standard non-HD FOV reconstructions. Outside the scan field of view data, is at least partly estimated by HD FOV .

The evaluations done with the Gammex phantom show that the results for diameter and CT number accuracy with HD FOV 5.0 are within the range of ± 40 HU and ± 3 mm that was reported for the predecessor algorithm HD FOV for the same setup⁵.

References

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