Region of Interest Reconstruction from Dose-minimized Super Short Scan Data

Yan Xia[1,2], Andreas Maier[1], Matrin Berger[1], Joachim Hornegger[1,2]

[1]Pattern Recognition Lab, FAU Erlangen-Nürnberg
[2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), FAU Erlangen-Nürnberg
yan.xia@cs.fau.de

Abstract. In this paper, we investigate an ROI image reconstruction in super short scan. The redundant rays in such scan are further shielded by using dynamic collimation. The acquired data coming with an extremely minimized radiation dose are sufficient for image reconstruction. For compensating resulting truncation, we apply a recently proposed algorithm - Approximated Truncation Robust Algorithm for Computed Tomography (ATRACT). The evaluation with two clinical datasets demonstrates that high image quality is achieved using this super short scan, with more dose reduction compared to a standard short scan.

1 Introduction

For many interventional procedures in neuroradiology, changes of the examined patient are often restricted to a small part of the full field of view (FOV). A restriction of the X-ray beam to only that area would significantly reduce radiation dose. In this paper we investigate an ROI image reconstruction in a novel acquisition scan coming with an extremely minimized radiation dose to the patient. Let us consider the 2D fan-beam geometry. Assume that the object support is a disk of radius R and the X-ray source rotates on the a circular trajectory $\boldsymbol{\alpha}(\lambda) = (D\cos\lambda, D\sin\lambda)^T$, where λ is the rotation angular range and D is the radius of circle. It is known that reconstruction is possible from projections acquired over an angular range $\Lambda_s = [0, \pi + 2\cdot\arcsin(R/D)]$. Such a projection interval is referred to as the short scan. The question is whether this short scan range can be relaxed when only a ROI is required to be reconstructed.

Noo et al. [1] reformulated a 2D FBP-type reconstruction of a ROI from X-ray fan-beam projections and showed that an exact reconstruction of the ROI can be achieved on an angular range less than a short scan. In this work, we adapt this concept into an ROI reconstruction. One advantage of our data acquisition is that the acquired projections can be truncated so that only the ROI is irradiated by X-rays. In order to compensate the resulting truncation artifacts, we apply the recently proposed truncation correction algorithm - Approximated Truncation Robust Algorithm for Computed Tomography (ATRACT) [2,3]. Although the algorithm is not mathematically exact, the shift-invariant feature is preserved and reconstruction of high image quality can be achieved [2].

To even further reduce radiation dose, we also adopt our prior work to the new data acquisition method. That is to deploy the dynamic collimation to shield the redundant rays during data acquisition [4]. The new data acquisition method, together with the truncation robust ATRACT algorithm, has various potential benefits, such as higher temporal resolution, lower patient dose, and reduced computational requirements.

2 Materials and Methods

In following sections we describe the two types of dynamic collimation which are applied in our new data acquisition system.

2.1 Asymmetric Collimation with Fixed Distance

In many clinical applications, the position of the ROI may not be located exactly around the iso-center of the patient, as illustrated in Fig. 1a. Dependent on the location of the ROI, the position of the collimator blades may vary from one angulation to the other (i.e., $u_1 \neq u_1'$ and $u_2 \neq u_2'$) while the distance between the blades does not change, i.e., $u_2 - u_1 = u_2' - u_1'$. We refer to this collimation as Asymmetric Collimation with Fixed Distance (ACFD). Such collimation can be generally applied for ROI imaging with off-center ROIs within the patient.

2.2 Asymmetric Collimation with Changeable Distance

It is known that a short scan measures data once in some views while twice in other views due to the fan-beam. The redundant data are weighted by a smooth weighting function, e.g. the Parker weights [5] before the filtering. In Ref. [4], we investigated the possibility to block redundant rays during short scan acquisition by successively moving the collimator into the ray path at the beginning of the scan. One requirement is the distance between the two collimator blades varies during the angulation, i.e., $u_2 - u_1 \neq u_2' - u_1'$, as illustrated in Fig. 1b. We

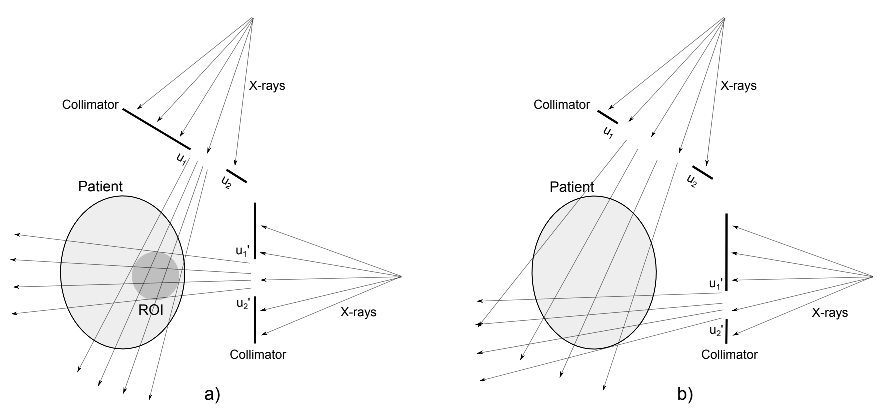

Fig. 1. Illustration of dynamic collimation: a) Asymmetric collimation with fixed distance (ACFD) and b) asymmetric collimation with changeable distance (ACCD).

investigate in this work an Asymmetric Collimation with Changeable Distance (ACCD) to block redundant rays in super short scans. Again, such collimation provides minimal complete data for reconstruction without redundancy, suggesting no weighting function is needed and further dose reduction is possible.

2.3 Super Short Scan Acquisition

Conventionally, a short scan acquisition is used when the entire object is to be reconstructed. However, the angular interval can be further reduced when only the ROI is required to be irradiated and reconstructed. Let us first consider the off-center ROI case in Fig. 2a and the corresponding short scan sinogram in Fig. 2b. When using the ACFD collimation to get the truncated projections to reconstruct the specific ROI, we will only obtain the curved band (including dashed curves) in the sinogram. Then, let us consider the data redundancy. We know that a short scan measures some redundant rays at the beginning and at the end of data acquisition in a fan-beam geometry and these redundant rays follow the relation $g(\beta, \alpha) = g(\beta + \pi + 2\alpha, -\alpha)$. This reflects on the sinogram: The data in the triangle area ABC are redundant to the data in $A'B'C'$, which means only one must be required to reconstruct the object. Therefore, the short scan angular range can be reduced and the acquisition can start at the point where the line AC intersects the ROI sinogram boundary since the scan segment below the intersect (shown in the dashed band) will be measured again at the area $A'B'C'$. This enables the reconstruction of the ROI over an angular range less than a short scan, i.e., super short scan.

The data acquisition is divided into two stages: 1) using ACCD to acquire the data corresponding triangle area 1 and 2) using ACFD to acquire the rest (area 2). It is important to note that the super short scan, together with dynamic collimation, is able to minimize the dose to the patient while acquiring non-redundant data for reconstruction. The angular interval for super short scan,

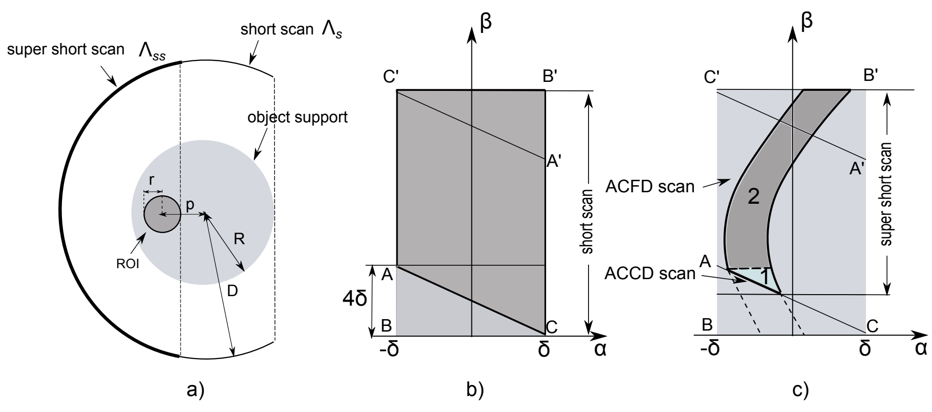

Fig. 2. a) Illustration of the short scan and the super short scan, b) and c) the corresponding sinograms.

i.e., $\Lambda_{ss} = [0, \vartheta]$, can be determined by the radius r and location p of the ROI:

$$\vartheta = \pi - 2 \cdot \arcsin\left(\frac{p-r}{D}\right) . \tag{1}$$

With increasing distance from the isocenter and decreasing ROI radius, the angular interval decreases. Note that when the ROI is located at the iso-center ($p = 0$) and the radius of the ROI is equal to the object support ($r = R$), the interval above extends to the short scan range Λ_s. The dose reduction can be approximated by computing the ratio between the short scan range and the difference of short scan and super short scan range plus half of the angular range to acquire the area 1 (since it is a triangle):

$$\gamma = \frac{2 \cdot \arcsin\left(\frac{R}{D}\right) + \arcsin\left(\frac{p-r}{D}\right) + \arcsin\left(\frac{p+r}{D}\right)}{\pi + 2 \cdot \arcsin\left(\frac{R}{D}\right)} . \tag{2}$$

For instance, for an off-centered ROI with radius $r = 22.5$ mm and location $p = 30$ mm acquired from a C-arm CT system with the standard configuration $D = 750$ mm, $\arcsin(R/D) = 10°$. The potential dose reduction is $\gamma = 12.2\,\%$.

2.4 ATRACT Algorithm

Both ACCD and ACFD collimation will result in truncation in all projections, which is not compatible to conventional reconstruction algorithms. Hence, we apply a truncation robust algorithm to deal with truncation problem [2,3]. The idea behind ATRACT is to adopt the FDK (Feldkamp, Davis, and Kress) algorithm [6] by decomposing the 1D ramp filter into two successive filter steps. Thus, the algorithm can be preformed as follows: 1) Cosine and Parker weighting of projection data; 2) 1D Laplace filtering of the pre-weighted data; 3) 1D convolution-based filtering with a kernel $\ln|u|$ to get the filtered projection data; 4) standard backprojection with a distance weighting to obtain the final volume.

2.5 Experimental Setup

We applied two clinical datasets of human head to validate and evaluate the proposed method. The datasets were acquired on a C-arm system with 496 projection images (1240×960 px) at the resolution of 0.308 mm / px.

Two experimental configurations were considered. In configuration 1, no collimation was applied, yielding the non-truncated short scan data. In the second one, the datasets were virtually cropped onto the centered and off-centered ROI, with $r = 22.5$ mm. The angular range of the super short scan is $\Lambda_{ss} = [0, 184°]$ for the centered ROI, and $\Lambda_{ss} = [0, 179°]$ for the off-centered ROI.

All clinical data were reconstructed onto a volume of $512 \times 512 \times 350$ with an isotropic voxel size of $0.45\,\text{mm}^3$. The standard FDK reconstruction of configuration 1, i.e. short scan non-truncated data were used as reference in each clinical case. The truncated datasets with super short scan were reconstructed by the ATRACT and FDK algorithm. To quantify retained accuracy obtained by the proposed algorithm, two quantitative metrics were used: the relative Root Mean Square Error (rRMSE) and the correlation coefficient (CC).

	Metrics	Super SS FDK	SS ATRACT	Super SS ATRACT
Centered ROI	rRMSE	42.1 %	4.66 %	4.84 %
	CC	0.14	0.96	0.96
Off-centered ROI	rRMSE	38.4 %	4.71 %	4.96 %
	CC	0.20	0.96	0.95

Table 1. Summary of quantitative analysis in two ROI cases (SS: short scan).

3 Results

The reconstructed results are presented in Fig. 3, 4 and the summary of quantitative analysis is tabulated in Table 1. As expected, the FDK algorithm can not handle the data acquired from configuration 2. Two types of artifacts are observed: a bright ring artifact at the border of the ROI and streaking artifacts within the ROI. The reasons for these artifacts are data truncation caused by ACFD and ACCD, respectively. An rRMSE of as large as 42.1 % confirms this observation. In contrast, the ATRACT reconstructions from configuration 2 are able to achieve high image quality. No significant difference within the ROI is found when comparing the reference to short scan and super short scan ATRACT reconstruction. The rRMSE is reduced to 4.84 % for truncated super short scan ATRACT, which is closer to its short scan counterpart (4.66 %). Both methods yield high CC values. This demonstrates that with the ATRACT algorithm, an ROI acquisition with a super short scan achieves reconstructions of high quality, while minimizing the radiation dose to the patient.

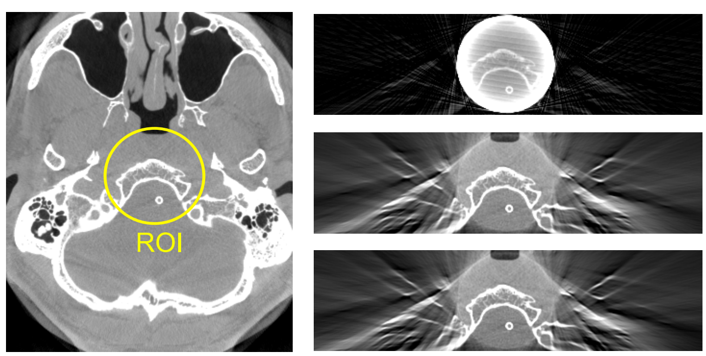

Fig. 3. Reconstructed results of the centered ROI dataset by the different algorithms. Left: the FDK reconstruction of non-truncated data; right from top to bottom: the super short scan FDK , the short scan ATRACT and super short scan ATRACT reconstruction.

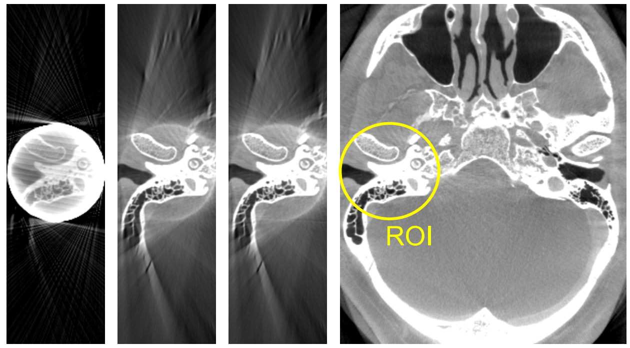

Fig. 4. Reconstructed results of the off-centered ROI dataset by the different algorithms. From left to right: the FDK reconstruction of super short scan data, the short scan ATRACT, the super short scan ATRACT and reference FDK reconstruction.

4 Discussion

In this paper we presented a new ROI acquisition method that acquires data in a super short scan using different types of dynamic collimation. A major advantage of this super short scan is that the acquired data satisfy both data sufficiency and non-redundancy with minimized dose to the patient. A limitation of the method is that it is only extended to the fan-beam geometry. For a circular cone-beam scan, the extension is not straightforward due to two reasons: the relation $g(\beta, \alpha) = g(\beta + \pi + 2\alpha, -\alpha)$ will not be held for the slices away from the mid-plane; discontinuous behavior of the dynamic collimation to the cone-beam data. Future work involves investigating these issues and extending the method to a cone-beam geometry.

References

1. Noo F, Defrise M, Clackdoyle R, Kudo H. Image reconstruction from fan-beam projections on less than a half scan. Physics in Medicine and Biology. 2002;47:2525–2546.
2. Dennerlein F, Maier A. Approximate truncation robust computed tomography - ATRACT . Physics in Medicine and Biology. 2013;58:6133–6148.
3. Xia Y, Maier A, Dennerlein F, Hofmann HG, Hornegger J. Efficient 2D filtering for cone-beam VOI reconstruction. In: Proc IEEE NSS/MIC; 2012. 2415-2420.
4. Xia Y, Berger M, Riess C, Hornegger J, Maier A. Dose Reduction Achieved by Dynamically Collimating the Redundant Rays in Fan-beam and Cone-beam CT. In: Proc IEEE NSS/MIC; 2013. To appear.
5. Parker DL. Optimal short scan convolution reconstruction for fan-beam CT. Medical Physics. 1982;9:254–257.
6. Feldkamp LA, Davis LC, Kress JW. Practical cone beam algorithm. J Opt Soc Am. 1984;1(6):612–619.