Portability of TV-Regularized Reconstruction Parameters

SIEMENS Healthcare

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Background and Purpose

In C-arm CT, severe artifacts may show in the reconstructed image due to a limited rotation angle and view projections during acquisition.

Iterative methods using Compressed Sensing [3] are designed to compensate those artifacts by **iteratively** alternating between backprojecting data into the reconstructed image and projecting intermediate reconstruction images back into the raw data domain.

The purpose of our work is to present insights about the data dependence of the combined method's parameters set by the user, introducing a high dimensional optimization space.

Key Ideas

Analyze the impact of changes to the TV constraint iterative reconstruction method's parameter set

- Define and validate suitable error metrics
- Select one optimal parameter set for given data
- Investigate the quality of the reconstruction with the parameter set on different data

Method: TV Constraint Iterative Reconstruction

Compressed Sensing deals with the problem of incomplete data by finding solutions to underdetermined linear systems.

- Takes advantage of the signal's sparseness or compressibility in some domain using sparsifying operator Ψ. [3]
- Sparseness can be incorporated into a constraint. [5]

During reconstruction the one solutions is chosen which transformed coefficient sequence also minimizes the $\ell 1$ norm, penalizing image artifact creation.

$$\min\ ||\Psi f(r)||_1 \text{ subject to } ||R\, f(r) - p||_2^2 < \epsilon \qquad (1)$$

Alternating optimization: iTV reconstruction approach. [4]

- SART [2] to minimize $||R\, f(r) - p||_2^2$
- Gradient Descent to increase the sparsity of $\Psi f(r) := \nabla f(r)$
- Linear combination of intermediate volumes $f_{n+1} = (1-\lambda) f_{n+1}^{SART}(r) + \lambda f_{n+1,M}^{TV}(r)$ after each iteration

An optimal parameter value $\lambda \in]0;1]$ is determined in the raw data domain by solving (3), since ϵ_{n+1} is known and ω constant.

$$\epsilon_{n+1} = (1-\omega) \cdot ||R f_{n+1}^{SART}(r) - p||_2^2 + \omega \cdot \epsilon_n, \quad \omega \in]0;1[\qquad (2)$$

$$||R[(1-\lambda) f_{n+1}^{SART}(r) + \lambda f_{n+1,M}^{TV}(r)] - p||_2^2 = \epsilon_{n+1}. \qquad (3)$$

Variables: Select one optimal parameter set

Star-shaped search for the optimal parameters using iTV

Type	β	ω	λ_{max}	iterations N	*regul*	α_{init}	GD-Iterations
default	.4	.8	1.2	20	10^{-4}	.3	25
changes	.8	.4	$\{5, \infty\}$	$\{10, 30\}$	10^{-2}	.8	10

The default parameters for the iTV reconstruction and it's variations. The best result for the FORBILD head phantom comes from the default set plus relaxation parameter $\beta = 0.8$. [1]

Metrics: Measure reconstruction quality

Measures used for 3D image comparison

- Root-Mean-Square Error
- Peak Signal-to-Noise Ratio
- Mean Structural Similarity
- Pearson Correlation
- Total Variation
- Eyeball Measure

Results

Reconstruction results with limited angle relative to ground truth or FDK in percent.

Simultaneous Algebraic Reconstruction Technique

Reconstruction results for the SART method, $\beta = 0.8$, $N = 20$.

	FORBILD head					Human head phantom				
	200°	185°	170°	155°	140°	200°	185°	170°	155°	140°
RMSE	56	50	51	51	47	58	49	56	57	54
PC	102	103	103	103	106	58	49	56	57	54
MSSIM	97	90	101	114	124	99	109	118	122	134
PSNR	156	172	156	164	209	142	145	141	148	147
TV	135	117	123	130	145	126	112	119	121	134

Improved TV Regularized Reconstruction

Reconstruction results for the iTV method

$\beta = 0.8$, $\omega = 0.8$, $\lambda_{max} = 1.2$, $N = 20$, regul $= 10^{-4}$, $\alpha_{init} = 0.3$, GD-Iterations $= 25$.

	FORBILD head					Human head phantom				
	200°	185°	170°	155°	140°	200°	185°	170°	155°	140°
RMSE	17	19	29	32	38	45	38	52	52	47
PC	102	103	104	104	107	102	104	105	105	110
MSSIM	141	132	149	169	181	112	123	131	137	159
PSNR	149	138	127	135	168	123	129	121	122	129
TV	57	50	46	46	48	41	36	29	30	34

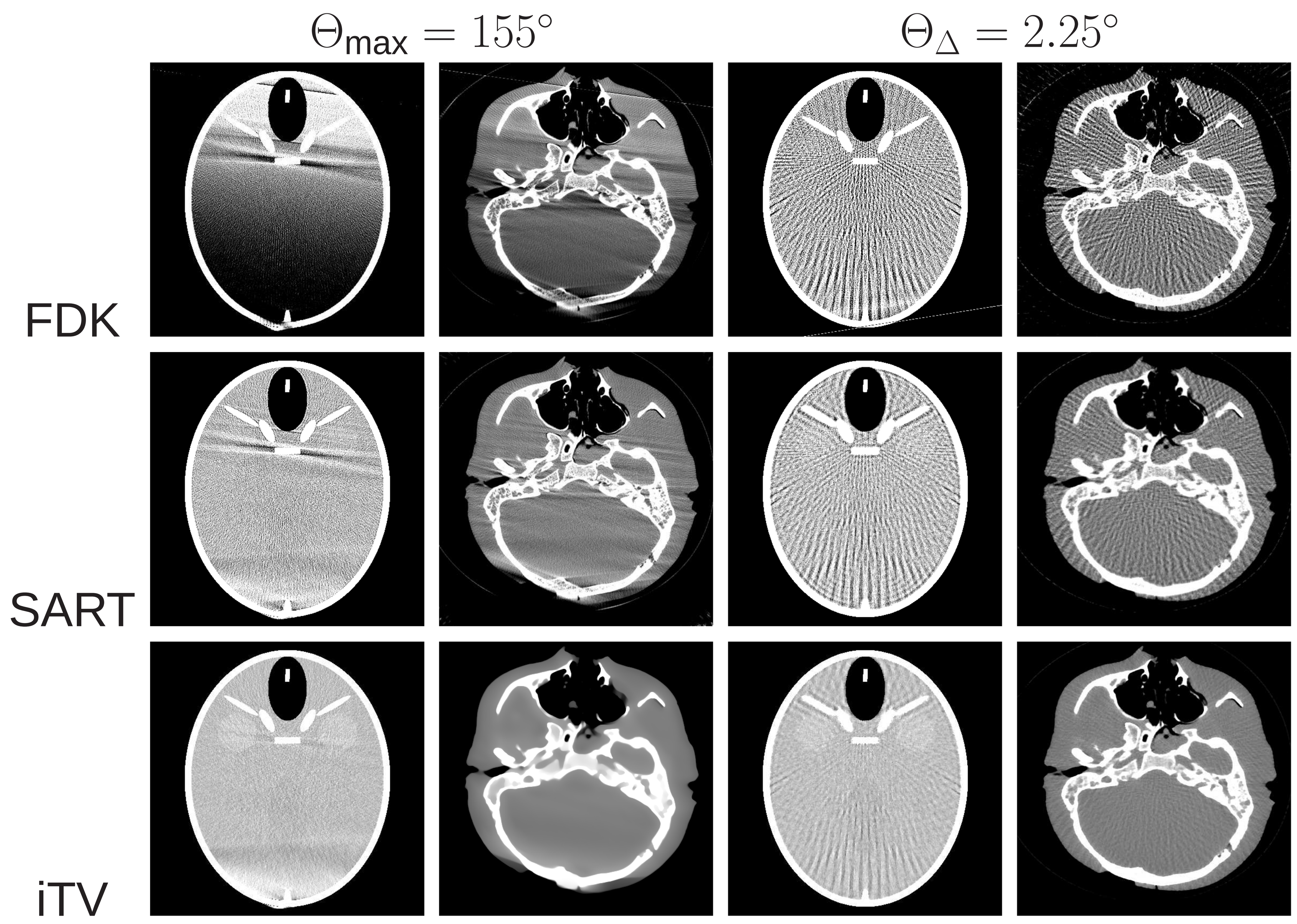

Figure 1: FORBILD head phantom and human head phantom reconstructions from limited angle ($\Theta_{max} = 155°$) and few projections ($\Theta_{\Delta} = 2.25°$). WC:0, WW:$\{200, 1000\}$

Conclusion

The fixed set of parameters **optimized for a limited angle** acquisition of the FORBILD head phantom was used during reconstruction of various scenarios.

The inhomogeneous regions resulting from the X-ray photon noise induced and streak artifacts are less prominent in iTV improving the perception of low contrast elements. However, the porous bone structure of the human head phantom got blurred significantly using the same set of parameters for this reconstruction.

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