Non-Rotational Tomography for Luggage Scanning using Krylov Methods

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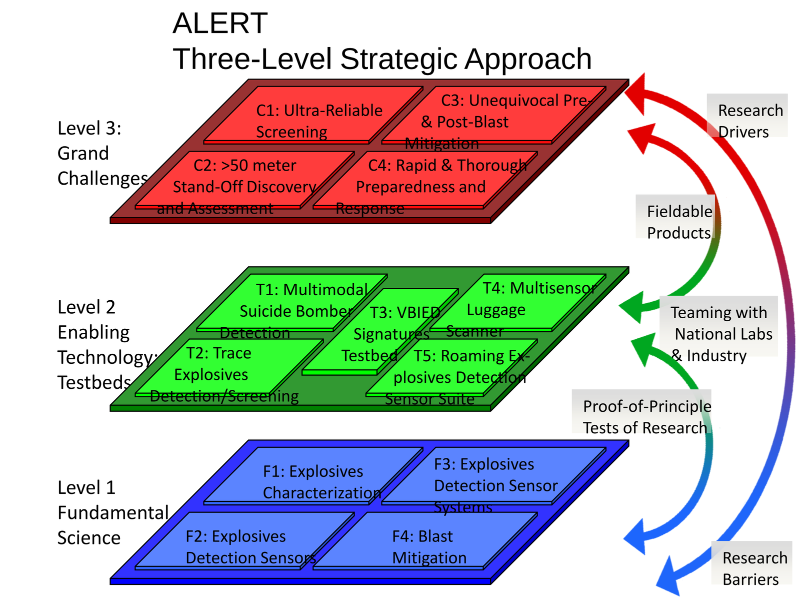


Goal

To develop a non-rotational tomography approach for the purpose of achieving CT results in environments constrained by space and power.

Motivation

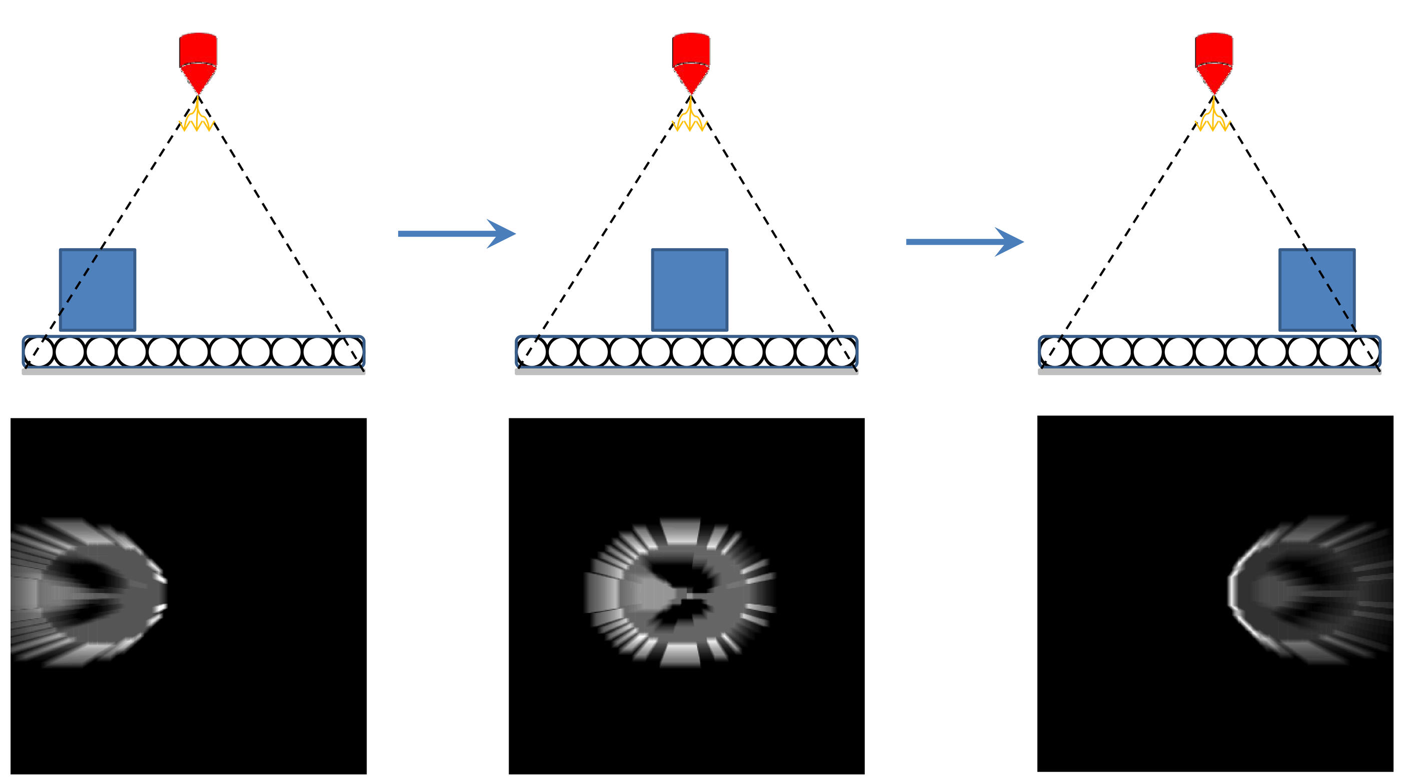
- Computed tomography has been at the forefront in providing detailed, quality 3D imagery in medical and security fields.
- X-Ray CT demand immense power and space requirements.
- Not all scenarios can afford to provide such requirements (i.e. carry-on luggage inspection, field clinics)
- Current machines such as the GE CTX9000 (Fig. 1) are too massive for carry-on applications and are confined to large rooms for checked bags

Capability

Size

Fig. 1: Left) CTX9000 DSI CT Machine, Dimensions: 16' x 8' x 7.5', for checked-bags
Right) Rapiscan 620XR Line Scanner, Dimensions: 7' x 4.5' x 3', for carry-on bags

Scanning Concept and Model



$r^1 = A^1 x$ $\qquad$ $r^{n/2} = A^{n/2} x$ $\qquad$ $r^n = A^n x$

Fig. 2: Three projections in a set of n

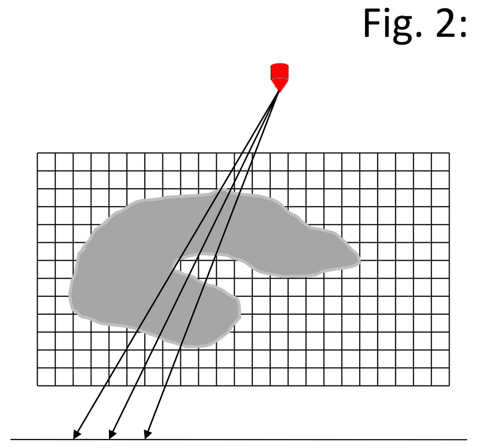


Fig. 3: Sample of ray traces to simulate for a given projection

Eq. 1: $r_i = a_i' * x$

Equation 1 is computed by using Siddon's ray tracing technique [1].

The problem is formulated by taking a series of projections at n different object positions (Fig. 2). Each row is computed as the ray trace of one projection line.

Reconstruction Challenges

1) Inconsistent Geometric Spacing

- Standard fan-beam projections have consistent spacing from projection to projection (Fig. 4).

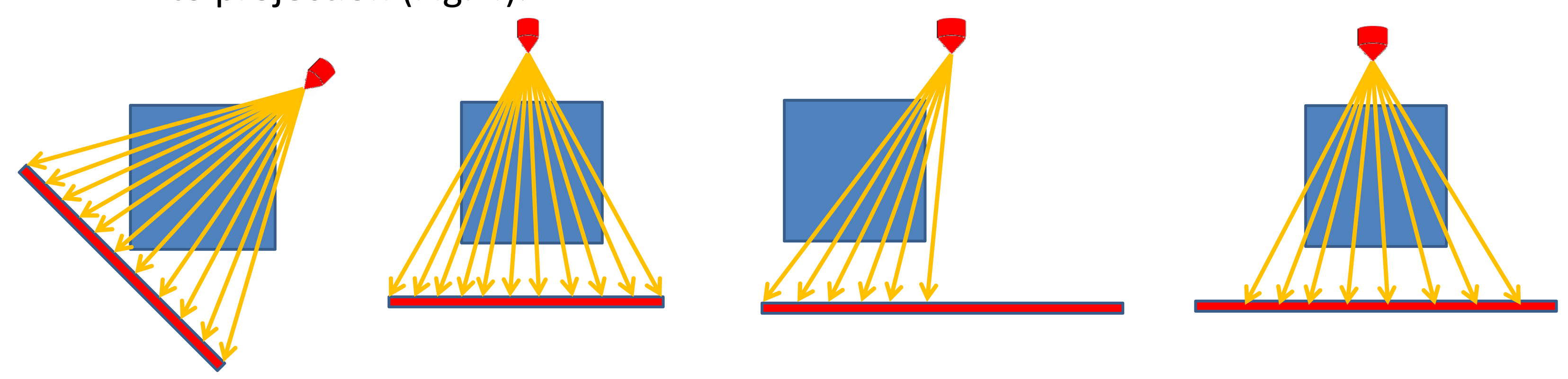


Fig. 4: a) 45° of fan-beam, b) 0° of fan-beam, c) Position 1 of non-rotational tomography, d) Position n/2 of non-rotational tomography

- One projection is similar to cone beam setups
- Linear geometry vs rotational geometry causes inconsistent ray spacings between projection data
- Direct methods such as Feldkamp-Davis-Kress (FDK) no longer apply.

2) Limited-Angle Tomography

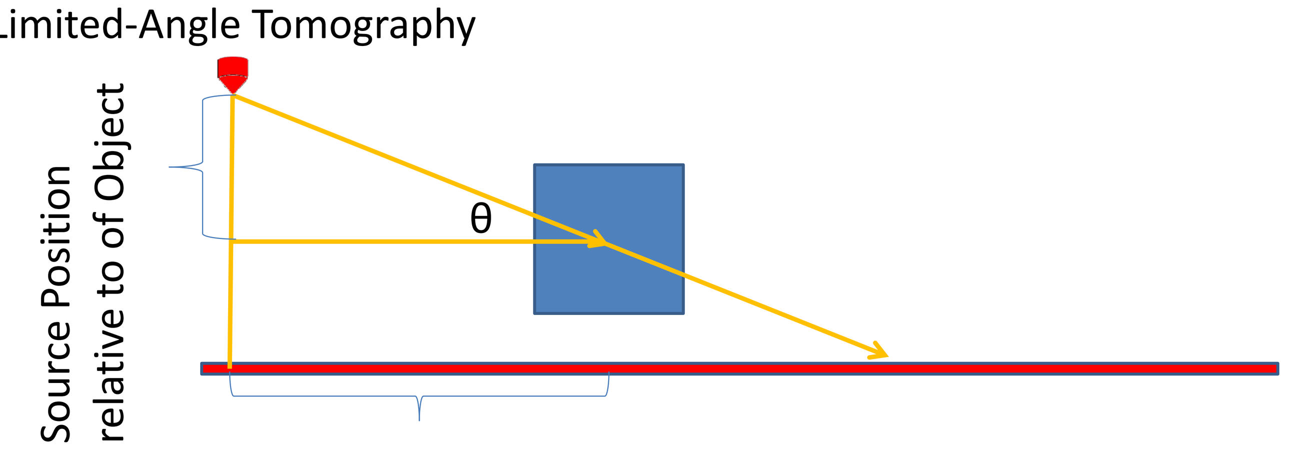


Fig. 5: Angle of Projection Relative to Source Position / Sensor Width

Eq. 2: $\tan(\theta)\ \alpha\ \frac{Source\ Position}{Object\ Position}$

The geometry of this setup is governed by simple trigonometry (Eq. 2). As a result to achieve a full 180° of projections, the only solution is to either have an infinite width sensor and a zero height source. Since both are infeasible this is by nature forced to be a limited-angle tomography problem.

Solution Approach

The set of ray traces from equation 1 are stacked together to form the whole system of equation (Eq. 3).

$$\text{Eq. 3: } \begin{bmatrix} r^1 \\ \vdots \\ r^n \end{bmatrix} = \begin{bmatrix} A^1 \\ \vdots \\ A^n \end{bmatrix} x$$

Efficient inversion via Krylov methods such as generalized minimal residual method (GMRES)[3] are used to solve the normal equations in equation 4.

$$\text{Eq. 4: } A'Ax = A'r$$

Results

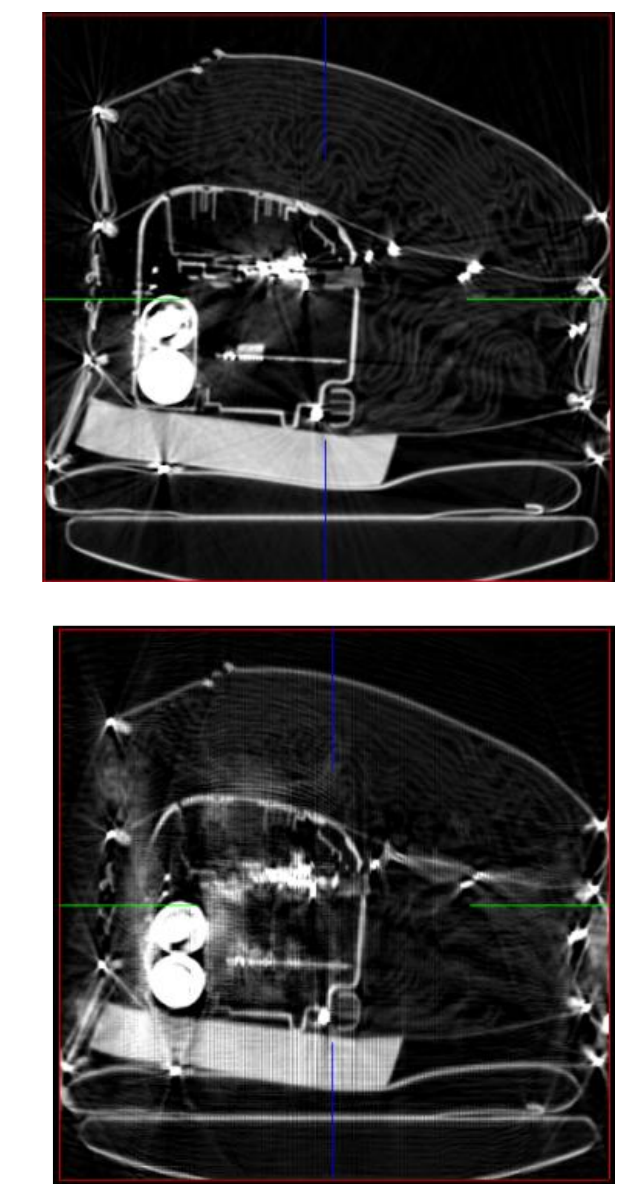
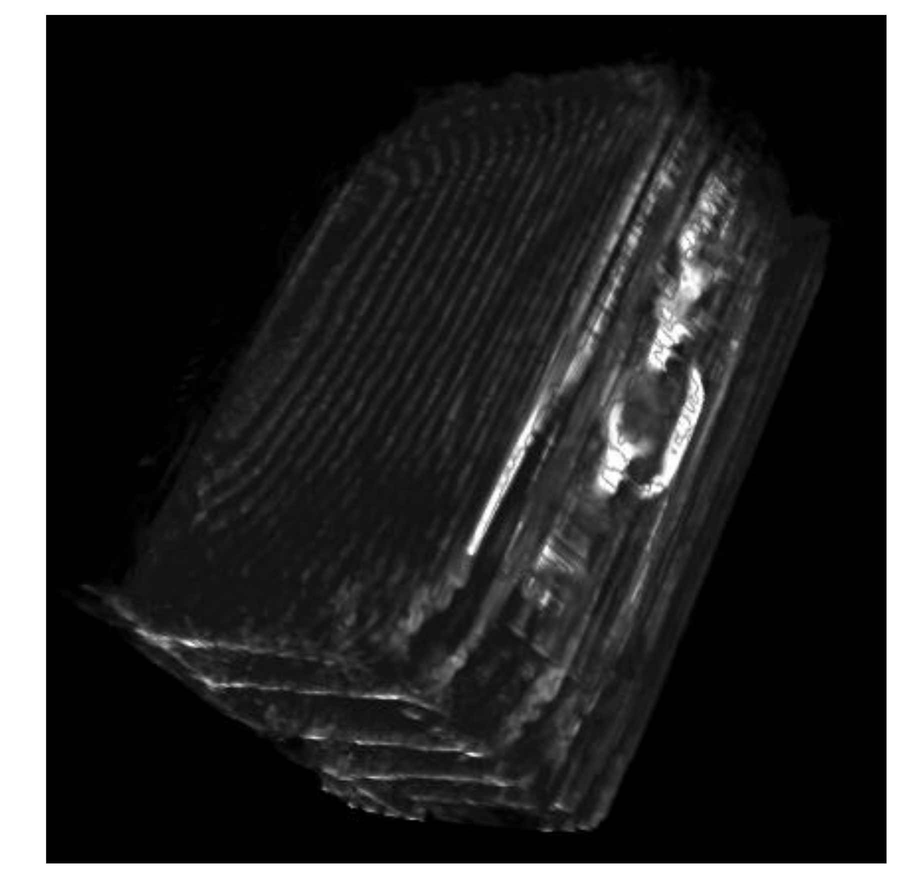


Fig. 6: Top – Test imagery from a helical CT scanner. Bottom – Reconstructed Imagery after 150 iterations of GMRES.

Fig. 7: 3D Render of Reconstructed Data



The suitcase data had a voxel resolution of 512x512x260.

Research to Reality

Next steps:

- Simulations with established phantoms.
- Physical implementation to acquire actual data.

Algorithm Development → Simulations with Industry Phantoms → Simulations with actual data → Physical Implementation

Conclusion

We have shown that this geometry is feasible using conjugate gradient on the normal equations. The suitcase was reconstructed somewhat adequately but 150 iterations still requires a significant amount of time. Our reconstructive technique is able to work with real problem sizes, but unfortunately takes significant amount of time to process the data.

We have tested this problem setup with conjugate gradient but other iterative methods should also be explored. In addition a preconditioner needs to be established to speed up the convergence rate. In addition the limitations of the geometry are not well established and such a parameter search would also be beneficial.

References
[1] R. L. Siddon, "Fast calculation of the exact radiological path for a 3-dimensional CT array," Med. Phys. **12, 252–255 1985.**
[2] Saad, Y., Schultz, M.H. (1986): GMRES a generalized minimal residual algorithm for solving nonsymmetric linear systems. SIAM J. Sci. Stat. Comput.**7**, 856-869