Preconditioning Linear Tomography in Explosive Detection

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Abstract

Current helical scanning computed tomography scanners provide detailed 3D imagery in the medical and security domain. However, these scanners often require significant power, cost, and space. Such computed tomography machines are impractical for many field based applications where space and power are often limited, such as security/customs portal screening or field medical clinics. Through the use of a conveyor belt, an X-ray point source, and a flat panel detector we can achieve linear tomography without the need of spinning gantries. However, due to the limited-angle nature of the setup, direct inversion methods are impractical and iterative methods are required. This however incurs a high degree of computational complexity and we seek a preconditioner to speed up the convergence rate of the iterative Krylov method GMRES. We propose a preconditioner that reduces the problem into a series of 2D slice reconstructions. Linear tomography will bring tomographic imaging capabilities to areas such as checkpoint screening or medical field clinics that were previously inaccessible due to the power and size requirements.

Relevance

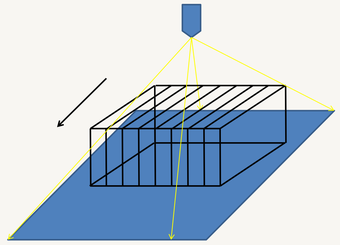
- Helical CT Scanners used for checked bags provide increased detection of threats and lower false alarms
- Due to power, size, cost constraints, helical CT machines are ill-suited for carry-on screening
- Direct methods such as Feldkamp-Davis-Kress are ill-equipped to handle the limited-angle tomography problem. Best to use model-based signal processing methods.
- Checkpoint screening will benefit from having tomographic images for luggage screening.

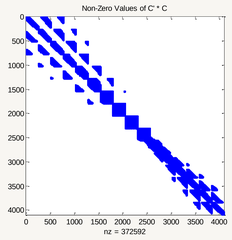
Technical Approach

Linear Tomography Model

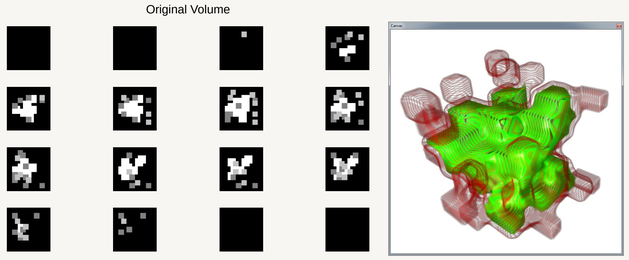
Geometric setup is modeled using Siddon's method to simulate x-rays while an object moves laterally across a conveyor belt, which can be set up as a system of linear equations. Inversion is solved by using the iterative Krylov method GMRES to solve the normal equations (Eq. 1)

$$Eq.1\ C^T C x = C^T y$$

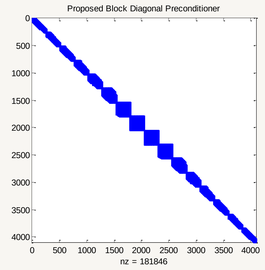


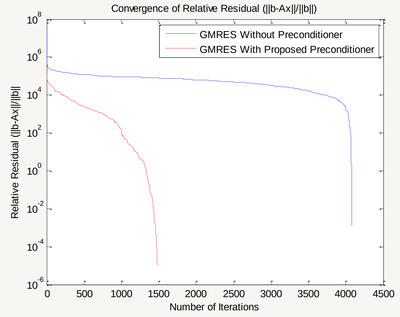


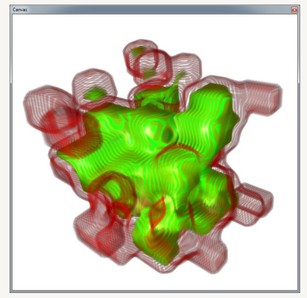
Simulated Volumetric Data



Each block diagonal element corresponds to solving the tomographic problem for a single slice



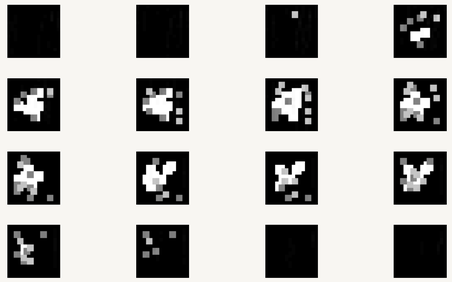




Reconstructed Render

Reconstruction without Preconditioner after 1400 iterations

Reconstruction with Preconditioner after 1400 iterations



Accomplishments Through Current Year

- Selected to present work at as part of DHS Science Conference's Student Day in Washington D.C.
- Poster presented at Boston University's Science and Engineering Day received Honorable Mention.

Future Work

- Explore means to speed up inversion of 2D slice reconstruction.
- Explore various regularization terms to improve reconstruction quality.
- Explore other means of parallelization to speed up computation via hardware.

Opportunities for Transition to Customer

- Developed ability to achieve linear tomography without large rotating gantries
- Tomographic imaging possible within power, size, and cost constraints of traditional line scanners
- Checkpoint screeners will be empowered with tomographic images to increase detection of threats and lower false alarm rates to improve passenger comfort during travels
- Doctors in constrained environments will benefit from having tomographic images to improve diagnosis of patient illnesses

Publications Acknowledging DHS Support

Sun, Z. & Karl, W. C. (2010). Non-Rotational Tomography for Luggage Screening Using Krylov Methods. Poster session presented at Research to Reality 11th Annual Research and Industrial Collaboration Conference; 2010 Oct 19; Boston, MA.

Sun, Z & Karl, W. C. (2011). Multi-View Linear Tomography for Explosives Detection in Carry-On Luggage. Poster presented at DHS Site Visit; 2011 Mar 24; Boston, MA

Sun, Z & Karl, W. C. (2011). A Non-rotational Approach to Computed Tomography. Presentation at DHS Science Conference – Fifth Annual University Network Summit; 2011 Mar 30; Washington D.C.

Other References

Saad , Youcef & Schultz, Martin H. (1986). GMRES: A Generalized Minimal Residual Algorithm for Solving Nonsymmetric Linear Systems, SIAM J. Sci. and Stat. Comput. 7, 856-869; doi:10.1137/0907058

Siddon, R. L. (1985). Prism representation: a 3D ray-tracing algorithm for radiotherapy applications. *Physics in Medicine and Biology*, *30*(8), 817-824. doi: 10.1088/0031-9155/30/8/005

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