

3D Imaging of Atom Clouds from 2D Projections

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Motivation

- Mid band gravity detectors such as the MAGIS[1] experiment rely on the imaging of the interfering atoms as they fluoresce from the excitation imparted by the driving laser.
- This project presents a novel opportunity to develop an imaging system that can not only monitor the position of the atom clouds, but also capture details of the 3D shape of the clouds at different points along the beam line.
- Advantage of using telecentric lenses is also probed for such imaging systems.

Background and Assumptions

- 2D projections of the clouds can be assumed to be true line integrals of the light emitted from the cloud along the dimension of the projection.
- 3D reconstruction can be done using iterative methods such as ADMM[2] and Conjugate gradients. Computational speedups can be achieved by restricting to the Visual Hull[3].

References

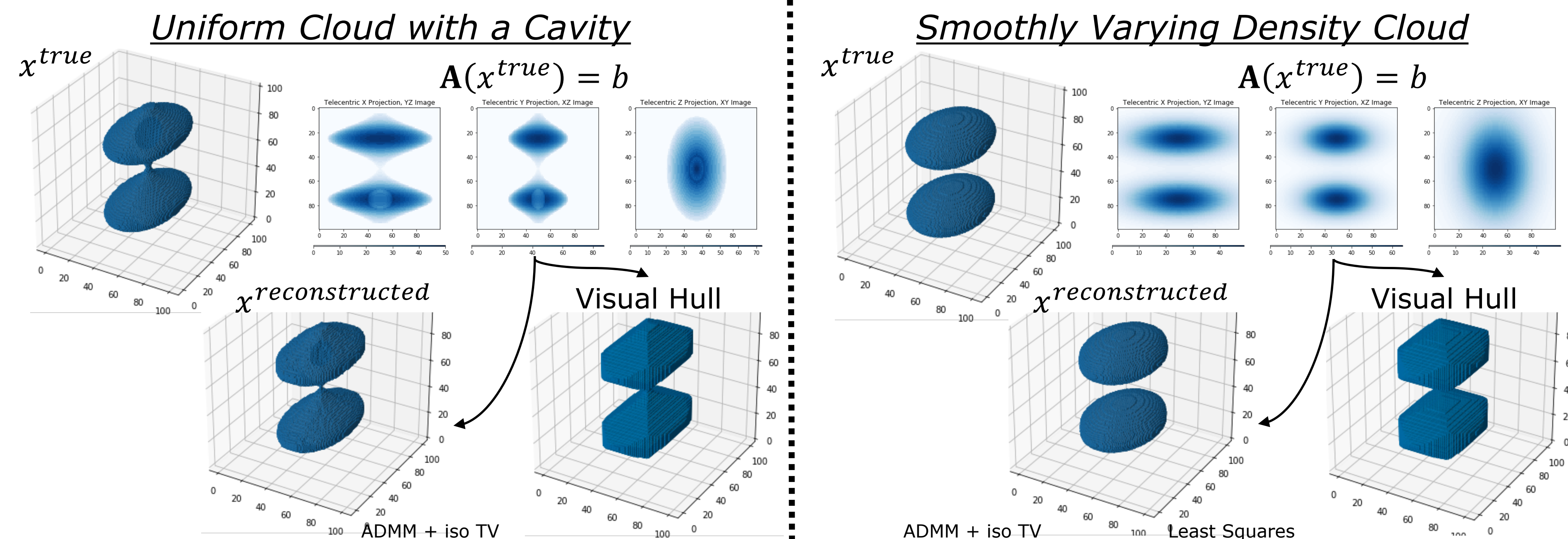
- [1] P. Graham, J. Hogan, M. Kasevich, S. Rajendran, "New method for gravitational wave detection with atomic sensors," PRL, 110, 17, Apr. 2013.
- [2] S. Boyd, N. Parikh, E. Chu, B. Peleato & J. Eckstein, "Distributed optimization and statistical learning via the alternating direction method of multipliers". Foundations and Trends in Machine Learning. 3 (1): 1–122[3], 2011
- [3] A. Laurentini, "The visual hull concept for silhouette-based image understanding," IEEE Transactions on Pattern Analysis and Machine Intelligence, 16, 2, Feb. 1994.

Experimental Technique

- The reconstruction problem is set up as an inverse problem in compressive imaging
- $\mathbf{A}(x) = b$ is being solved for an underdetermined system, hence priors are used
- Minimize $\frac{1}{2} \|\mathbf{A}(x) - b\|_2^2 + \Gamma(x)$, where $\mathbf{A}$ is the projection operator and,
 - $\Gamma(x) = \|D^1(x)\|_2^1$ for uniform density clouds; want sparse gradients/ uniform densities
 - $\Gamma(x) = \|D^2(x)\|_2^2$ or $\|D^2(x)\|_2^1$ for smoothly dense clouds; want slowly varying densities

Experimental Results

- Simulations of atoms clouds are used to evaluate the reconstruction techniques
- We consider 2 canonical clouds, one each for uniform and smooth density cases



telecentric entocentric	$\ D^1(x)\ _2^1$	Visual Hull Only	$\ D^2(x)\ _2^1$	$\ D^2(x)\ _2^2$	Visual Hull Only
PSNR	25.95/20.90	16.96/11.76	33.89/32.08	29.21/8.956	18.69/12.49
Recon Err	.0686/.1314	.1700/.5639	.0246/.0361	.0769/2.523	.1146/.4780

$$\text{PSNR} = 10 \log_{10}(1/\|voxel_{reco} - voxel_{true}\|^2)$$

$$\text{Recon Err} = \sum \|voxel_{reco} - voxel_{true}\|^1 / \sum voxel_{true}$$