Compressed Point Cloud Visualizations

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- Description of The Problem
- Description of The Wedgelet Algorithm
- Statistical Preprocessing
- Intrinsic Point Cloud Simplification
- Validation
- Planned Languages and Hardware

Survey aircraft equipped with a LIDAR range detection system produce maps of terrain consisting of millions of non-uniformly sampled points in $\mathbb{R}^3$. This list of points is referred to as a **Point Cloud.**

$P = \{(x_1, y_1, z_1), (x_2, y_2, z_2), ..., (x_n, y_n, z_n).$

Ideally this point cloud could be converted to an image and transmitted in real time. Currently however, techniques for producing viewable images from point cloud data sets are neither time or memory efficient.

- Regression techniques such as LOESS, which approximates the manifold locally using low degree polynomials produce good visualizations but do not admit a compact representation.
- Techniques which approximate the function piecewise on arbitrary adaptive meshes also do not admit a compact representation since the mesh is unknown to the receiver.

The goal of this project is to implement the wedgelet image transform on a LIDAR point cloud corresponding to urban terrain to create a highly compressed representation of the image. Additional preprocessing algorithms will be implemented to attain additional compression and improve image fidelity.

The idea behind wedgelets was first described by Donoho in [1] as a way to encode images in the cartoon class, piecewise constant images with C_2 boundaries between discontinuities. The goal of wedgelets was to be able to capture directional data present in an image which wavelets are unable to capture.

Wedgelets work by inducing a dyadic partition of an image, a tiling of the image space using squares of not necessarily constant size. On each square a line is drawn seperating the square into disjoint regions called wedges. Each wedge is then fitted with a constant value.

Figure: Original Grey Scale Image of a House[3]

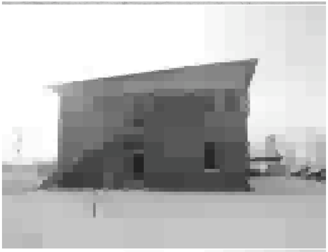

Figure: Wedgelet Transform using 1000 Wedges [3]

Wedgelets are provably quazioptimal when used on images of a class similar to the class we are interested in[1]. Namely data with a large geometric component such as urban topography. The line through each dyadic square essentially serves an an edge detector. Once the two discontinuous regions are separated they can be well approximated using a finite element space containing few degrees of freedom.

Theorem

Laurent: Let f be a piecewise constant with C^2 boundary. Assume that the set L_j consists of all lines taking the angles $\{-\frac{\pi}{2} + 2^{-j} l\pi : 0 \leq l \leq 2^j\}$. Then for $N \in \mathbb{N}$ there exists a wedgelet approximation (g, W) with $|W| \leq N$ and $||f - g||_2^2 \leq CN^{-2}$.[3]

Wedgelets allow a very compact representation by taking advantage of the quadtree structure induced by the dyadic partition and by using approximating functions containing few degrees of freedom.

One disadvantage of using raw point cloud data as opposed to gridded data is the increased presence of sensor noise. Most of this noise consists of incorrect extreme values and gaussian white noise. Wedgelets has demonstrated some ability at eliminating white noise[2].

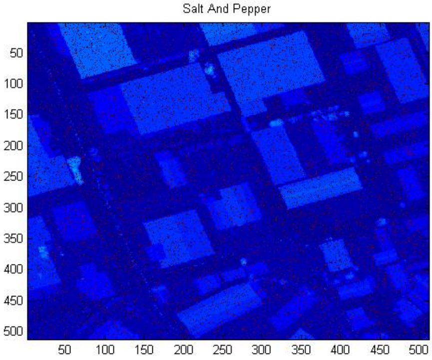

Figure: Salt and Pepper Noise 10 percent distribution

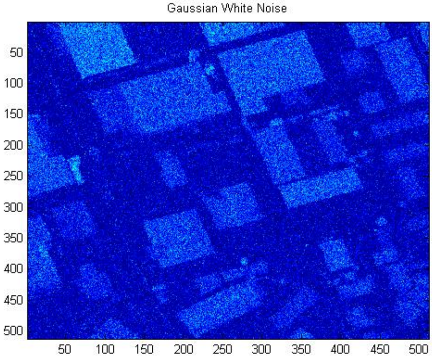

Figure: Gaussian White Noise $\mu = 0, \sigma = .005$

Several algorithms have been proposed for the elimination of statistical outliers from laser point clouds.[5] Any algorithm that is implemented must be able to act on the point cloud at multiple scales. It must also be able to distinguish true outliers from discontinuities inherent in the data.

One disadvantage of the wedgelets transform is its computational complexity. For large data sets the algorithm will be required to perform tens of thousands of least squares regressions on data sets as large as ten million points.

Moenning and Dodgson[4] have proposed an algorithm that removes redundant points from a point cloud data set. The algorithm is based on the idea of 'farthest point sampling.'

- A reduced data set makes the task of generating an image or compact representation from the point cloud much easier.
- This is particularly important given the complexity of the wedgelet transform.

This algorithm is robust in the sense that it can be applied locally without fear of "over deleting" elements from the cloud. There is a built in user defined minimal density guarantee that can be applied at all scales of the image[4].

- This is important because if a particular section of the point cloud is overly thinned then the existence of a unique linear least squares fit cannot be guaranteed on that section.
- This would make wedgelets useless on that section of the point cloud.

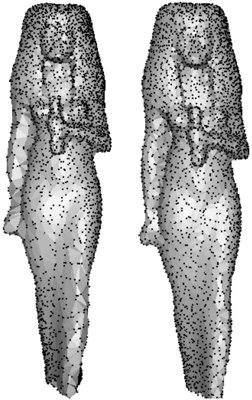

Figure: Example of Moenning and Dodgson's Point Cloud Simplification Technique[4]

Validation is to be accomplished in three steps:

- Analytic Proofs
- Implementation on a known image
- Comparison with Images from the USGS Archives

- Donoho[1] and F uhr [3] demonstrate strong error bounds for wedgelets under the assumption that the domain space is continuous.
- Moenning and Dodgson do not include any analytic error analysis with the description of their algorithm
- We would like to provide similarly strong error bounds on the Wedgelet algorithm assuming a discrete image space, and to perform a mathematical analysis of the error introduced by Moenning and Dodgson's point cloud simplification technique.

This stage of validation we will take a given gridded image and represent it as a point cloud. The compression algorithm will then process the point cloud. The resulting image should be similar to the image resulting when wedgelets is run on the original gridded image.

The algorithm will process a point cloud taken from the USGS archive. The resulting image will be compared to a DEM (Digital elevation model) of the same region.

- The primary language will be C++
- Some MATLAB will be used for visualization

The recursive nature of the Wedgelets algorithm makes it a prime candidate for paralyzation. Currently the planned hardware consists of two windows PCs with dual core 2.33GHz Intel Xenon processors.

- David L. Donoho *Wedgelets: Nearly Minimax Estimation of Edges*, The Annals of Statistics, Vol. 27, No. 3. (Jun., 1999), pp. 859-897.
- Laurent Demaret, Felix Friedrich, Hartmut Fhr, Tomasz Szygowski, *Multiscale Wedgelet Denoising Algorithms*, Proceedings of SPIE, San Diego, August 2005, Wavelets XI, Vol. 5914, X1-12
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- Moenning C., Dodgson N. A.: *A New Point Cloud Simplification Algorithm*. Proceedings 3rd IASTED Conference on Visualization, Imaging and Image Processing (2003).
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