Blended, Cross-Domain Algorithms for Improved Hydrographic DEMs

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***Abstract*—Hydrographic data are increasingly fused together with above-water remote sensing imagery such as from photogrammetry, Lidar, multispectral and acoustic data. This is facilitating a need to accommodate cross-domain tools and to visualize results in two-, three- and four-dimensional environments. However, added value is emerging in these sophisticated and evolving solutions. Presented here is one such result where bathymetry is augmented using a Poisson surface produced in similar manner as in Lidar processing, gaming and simulation.**

The bathymetry data originate from a hydrographic survey that was conducted to evaluate sonar hardware and sonar mount performance. This exceptionally high-quality survey from Lake Tahoe includes a variety of bottom types and steep slopes, coupled with oversampling to produce multibeam point densities ranging between hundreds to tens of thousands of points per meter. Conventional workflows producing a digital elevation model struggled to produce even a half-meter digital elevation model. We decided to introduce the Screened Poisson Reconstruction Surface into the workflow, and the resulting output is a variable density digital elevation model exceeding the resolution of a conventional approach.

***Index Terms*—hydrography, bathymetry, Lidar, Poisson, fusion**

I. Introduction

A point-cloud based approach is applied to post-processed multibeam bathymetry data to demonstrate an experimental workflow where the Screened Poisson Surface Reconstruction is applied, leading to improved resolution in the resulting digital elevation model (DEM). Surface construction is a fundamental step in Lidar data processing. A modern surface reconstruction designed for high-density point cloud data is the Cloth Simulating Filter [1] that is often used with Lidar data. We apply the more established Screened Poisson Surface Reconstruction [2] instead of the Cloth Simulating Filter in this study because it is fundamental to graphic processing, considers all the points at once without resorting to heuristic spatial partitioning or blending, and is therefore highly resilient to data noise – The Screened Poisson Surface Reconstruction allows for a more objective investigation in applying Lidar filters to bathymetric point clouds. We are focusing only on the application of the Graphics/Lidar workflow to the bathymetric data herein and plan to later integrate bathymetry an lidar data point clouds using a more sophisticated approach.

A special hydrographic platform having CAD models of the vessel, sensors and mounting hardware was configured to investigate installation and sensor optimization. As such, the built platform was deployed in a complex geologic environment having diverse bottom types, steep slopes, and a significant vertical relief such as that illustrated in Fig 1. The

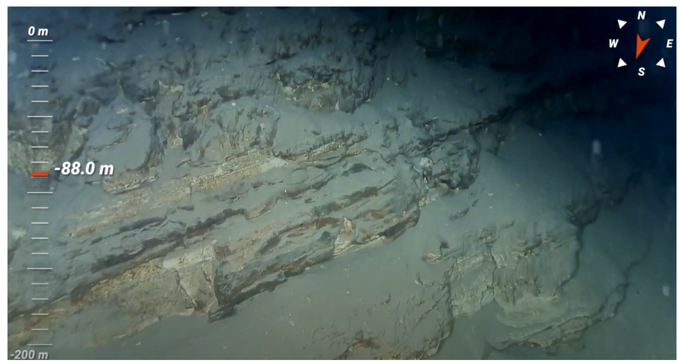

Fig. 1. The complex geomorphology of the environment presents a difficult challenge to creating a DEM.

surface elevation of Lake Tahoe has fluctuated dramatically over geologic time. These fluctuations are evident by the sub-aerial erosion of the deep canyons through the ancient sedimentary rocks in Rubicon Bay. Some of the rock layers exposed in the canyon walls are better consolidated and more resistant to erosion. These more resistant layers form small vertical *cliffs* in the canyon walls while the less resistant layers form the lower angle slopes between the cliffs, similar to the Grand Canyon in Arizona.

And, while the underlying purpose of hardware tuning and performance in a challenging setting is out of scope here, the resulting dataset presents an opportunity to evaluate a point-cloud based approach to producing a DEM that both exceeds the capabilities found in conventional hydrographic software. The results provided herein aim to invite inspired collaboration into multidomain algorithm design focused on the integration of remote sensing data prior to generation of a DEM.

II. Methods

A. Bathymetric Data

The survey included Rubicon Bay and Meeks Bay on the West shore of Lake Tahoe. This area of Lake Tahoe was exposed to Pleistocene glaciations, which fed large outlet

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glaciers that flowed in the Tahoe basin through all of the major drainages along the west side of the lake. The acquisition platform included a R2Sonic 2024 with Integrated Navigation System (INS) using Applanix POSMV Wavemaster on a Universal Sonar Mount HighTower model.

B. Workflow

The challenge with this intentionally hyper-dense dataset is that there are limited industry-based solutions capable of visualizing the data without loss of intrinsic detail. The dataset was collected by intentionally manipulating sonar angle and sampling rate to facilitate capturing steep, deep slopes. Conventional rendering struggles to preserve intrinsic detail due to the use of vector-to-raster algorithms not optimized for such detail. Figure 2 shows a portion of the dense but variable point cloud used in this study. This figure also represents the post-processed multibeam point cloud before having any further augmentation, and it clearly shows a relationship between physiology and point density.

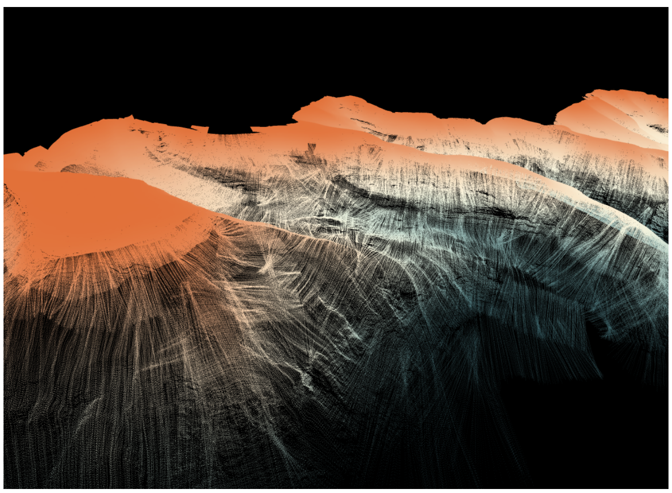

Fig. 2. Post-processed bathymetric point cloud showing variable point density in a complex setting. The complex geomorphology of the environment presents a difficult challenge to creating a DEM. Notice how the point cloud density varies significantly between the shallow, flat areas and the deeper, steeper areas. Fig. 3 provides a quantified representation of this variability.

The employed workflow uses PDAL [3], GDAL [4] and QGIS [5]. PDAL pipelines are used to render several GeoTIFFs. Preliminary GeoTIFF images are produced to show the nominal nearest neighbor distance density shown in Fig. 3. The nominal point spacing is calculated for every point by averaging the distance between any given point and its fifty nearest neighbors. The result is a GeoTIFF heatmap showing variable point density, quantifying the optimal resolution as it varies over the dataset. The red areas in Fig. 3 exceed several thousand points per meter while the blue areas yield more conventional point densities and down to as few as ten samples per meter. The variable point density is governed by the physical relief of the surface being imaged, shallow water features causing the sonar to ping faster than its already small sampling interval. The nominal neareast neighbor GeoTIFF

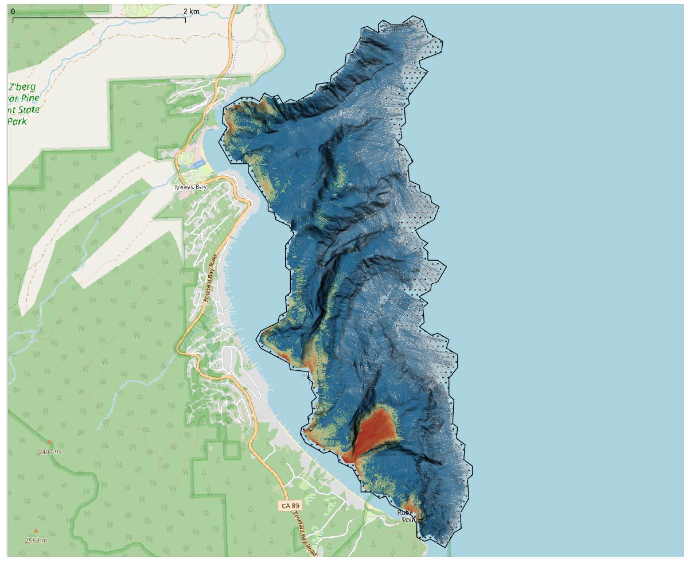

Fig. 3. Nominal Nearest Neighbor Density over 1-m bathymetric surface. The areas in red indicate a point density exceeding 10,000 samples per meter where the blue areas indicate a point density averaging below 10 samples per meter.

is used to steer configuration of the octree depth parameter that is fed into the Screened Poisson Surface Reconstruction. Octrees are most often used to partition a three-dimensional space by recursively subdividing it. The authors plan to explore automated determination of this parameter and do not do so here as it is out of scope of this study. We do, however, manually set the maximum octree depth to be used in the Screened Poisson Surface Reconstruction to a depth of sixteen.

III. Results

The output of the Screened Poisson Surface Reconstruction using a octree depth of sixteen is a point cloud that is larger than the original point cloud, every point existing on an imaginary, water-tight surface that passes through all of the original points. The synthesized points may be appended to the original points or handled separately. We chose to merge the points and create a twenty-centimeter grid, allowing the original points to augment the output in areas having low point density. Interestingly, the Poisson Surface did not exceed the point density in areas where the original points already exceeded thousands of point per meter. Therefore, merging the synthesized and original points also allows for improved data-driven resolution in low point density areas without creating artifacts in high point density areas. The before-and-after effect of applying the Screened Poisson Surface Construction to the multibeam bathymetry point cloud can be seen in Figures 4 and 5. It is clear that this is an exceptional dataset in both figures. However, figure 5 is able to produce a DEM at a higher resolution. It even becomes difficult to see the full effect without significantly zooming into the data.

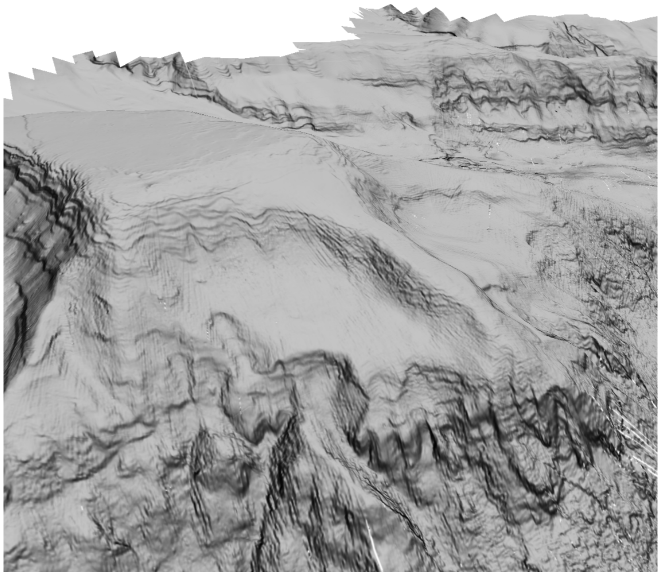

Fig. 4. Conventional data processing and one-meter resolution DEM. Several, time-consuming iterations with conventional software struggle to even produce the quality found in this oversampled multibeam point set.

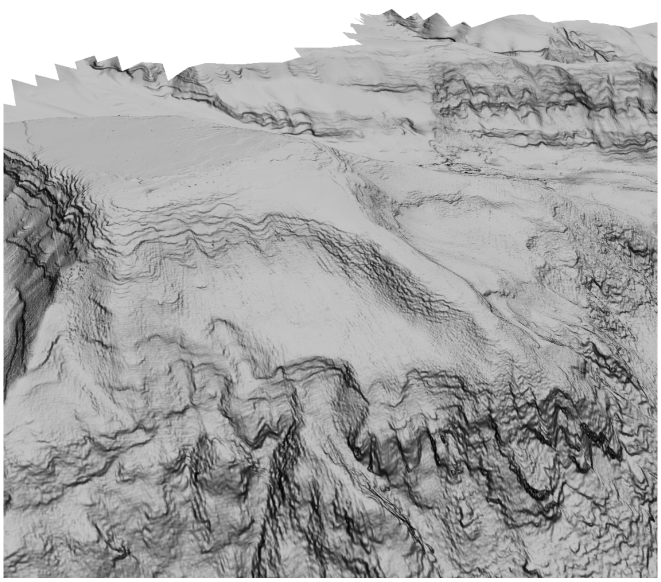

Fig. 5. Twenty-centimeter resolution achieved using the Screened Poisson Surface Reconstruction.

IV. Summary and Discussion

The twenty-centimeter color-relief DEM in Fig 6 is created using GDAL's gdaldem color-relief tool. What is notable about the results are that the bathymetric point cloud and rendered GeoTIFF are both enhanced by the single surface reconstruction using PDAL, making integration with above-water Lidar and photogrammetry less problematic in both PDAL and GDAL. Having high-density point clouds above and below the water line enables them to be merged either before or after applying any domain-specific algorithms. Figure 7 shows colorized comparison of conventional and enhanced DEM using the surface resconstruction approach. Further, the approach allows for localized areas to be created at much higher resolution where applicable. Referring back to Fig. 3, the dataset used here offers millimeter resolution in the shallow, red areas to meter resolution in the deeper, blue areas. Further, the reconstructed surface intersects the original points and there are no vertical artifacts above the survey tolerance (i.e. vertical errors are between one and three inches).

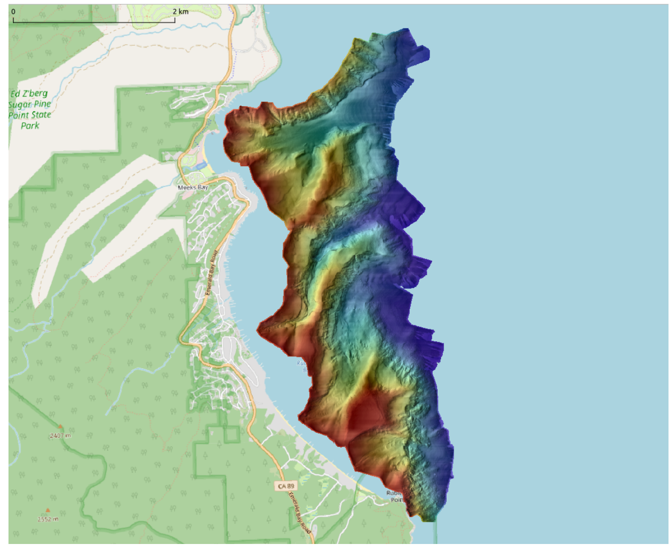

Fig. 6. Final, color-relief twenty-centimeter resolution achieved using the Screened Poisson Surface Reconstruction.

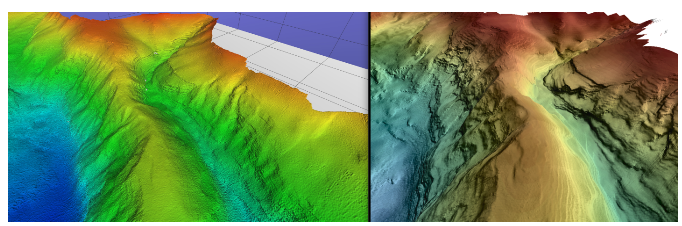

Fig. 7. One-meter DEM on the left from conventional processing. Twenty-centimeter DEM on the right using the Screened Poisson Surface Reconstruction.

A. Next Steps

It is increasingly common for multi-domain integration remote sensing data. This study demonstrates using the Screened Poisson Surface Reconstruction typically applied in a Lidar workflow to improve a DEM originating from a variable-density, high-density bathymetric point cloud. The results are promising and present numerous opportunities for innovation. Follow-up studies include merging bathymetry and Lidar, the application other algorithms such as the Cloth Simulating Filter, designing a workflow to correlate artifacts in the DEM to a digital twin of the hydrographic platform using the CAD models and acquisition datagrams, and the development of new multi-domain file standards allowing faster, simpler integration of data streams targeting above and below water line remote sensing.

We hope this study inspires deeper interest and investigation into merging algorithms that enable new insight into natural processes being observed through multiple technologies today. Our goals include a deeper dive into algorithm design that is inclusive of various remote-sensing algorithms. We welcome any interested or similar studies to reach out in an effort to explore this topic with deeper academic rigor, and will continue at our pace in the absence of more collaborators.

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