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Civil and Coastal Engineering Department
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An Overview of Lidar Point Cloud Processing Software

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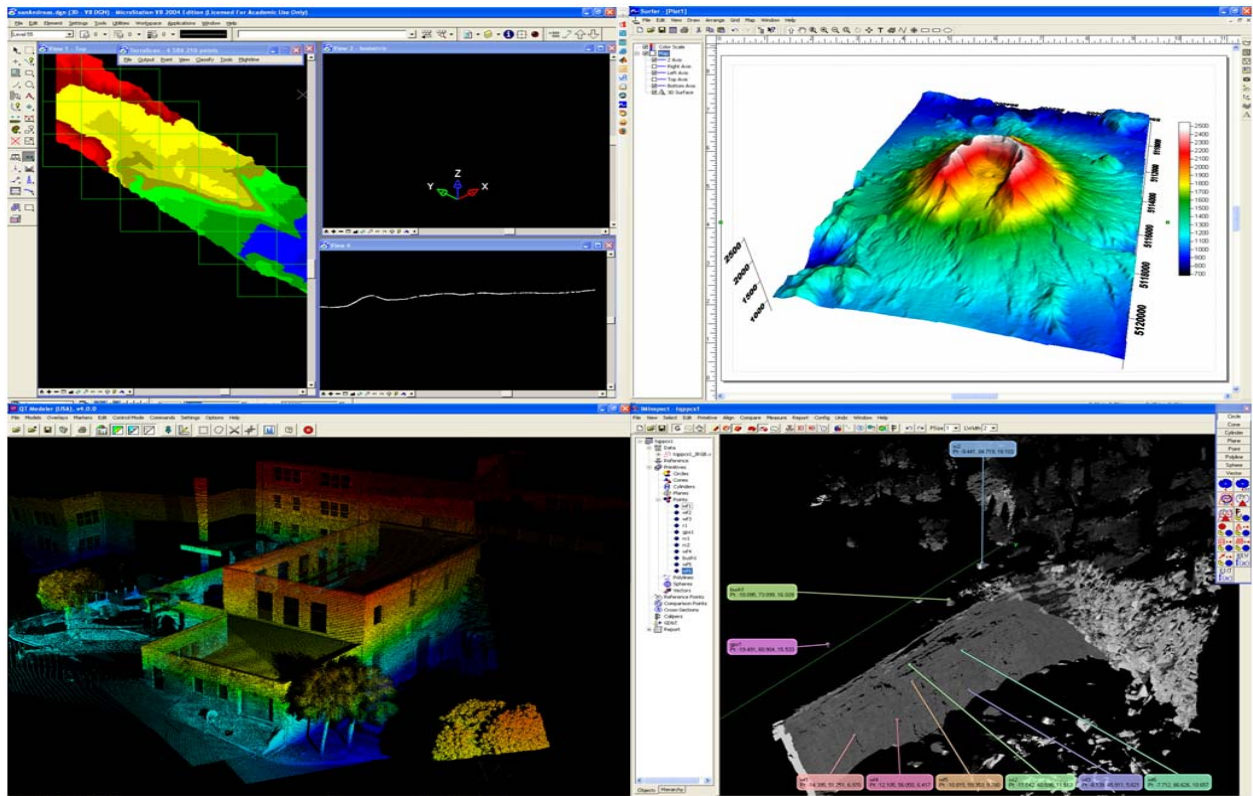
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1. Introduction

The Geosensing Engineering and Mapping (GEM) Research Center of the University of Florida is a pioneer and leader in the acquisition, processing and analysis of LIDAR and other types of geosensing data sets. Its research aims to improve and develop new equipments, techniques and algorithms for the general advancement of science and the mapping industry. It also provides support to geoscientists, engineers and planners on how LIDAR can be used to increase the efficiency and accuracy of their activities. On this line, one of top inquiries received by the center is related to which software is the recommended for the processing of point clouds for specific or general projects. To this question there is no unique answer; it depends on many aspects like budget, user needs

requirements and experience, activities to be performed, amount of data to be handled, available computing power and expected results to mention a few.

This report is aimed to provide prospective and experienced users of LIDAR data sets with an overview of some of the processing software that are available, so that the reader can make an informed decision on which one best fits its needs and requirements. Before describing the individual software packages is important to provide an outline on what are typical operations performed on a LIDAR point cloud. On the first part of the report the visualization, segmentation, classification, filtering, transformations, gridding and mathematical operations are summarized. Then on the main part of the report several of the most common processing software and on which the GEM center personnel have tested are described. The description includes the main purpose of the software, what type of operations can the software perform and what are its main advantage and limitation. Finally a software comparison table which summarizes the processing capabilities of each one is provided.

2. Typical operations performed on LIDAR point cloud data.

The point cloud is the first data product of any LIDAR instrument. In its crudest form is just a collection of range measurements and sensor orientation parameters. After an initial processing the range and orientation for each LASER shot is converted into a position in a 3D frame of reference and this spatially coherent cloud of points is the base for further processing and analysis. Additional to the spatial information some LIDARs provide for each point texture or color information; this can come from the intensity of the reflected laser signal or from a coregistered imaging sensor. The combination of 3D spatial and spectral information contained in the data set allows great flexibility to perform manipulations to extract the required information. Some of the basic manipulations or operations that can be performed on a Lidar point cloud are described next.

2.1. Visualization

The first thing that you would like to do to a new LIDAR dataset is to look at it. Visualization is the most basic operation; however, a good visualization allows the analyst to assess the quality of the dataset, it enables the planning and control of different processing schemes and finally will provide the presentation of the final product. Most LIDAR processing software will have a graphical interface that will render the numerical point cloud into an image, but there is a great range of options and functionalities that will vary among the different options. The simplest visualization will plot all the points with a single color and size, and the operations of Zoom, Rotate, and Navigate will be available. More advanced software will render each LIDAR point according to other characteristics, it can be brightness coded according to the laser return intensity, or RGB textured if the point cloud was coregistered with a digital image, it can also be color coded according to elevation, range, class or any other

attribute contained in the point cloud structure. Some software will allow the user to toggle between the rendering of the point cloud and the rendering a Triangulated Irregular Network (TIN) or Digital Elevation Model (DEM) generated from it as illustrated in Figure 1.

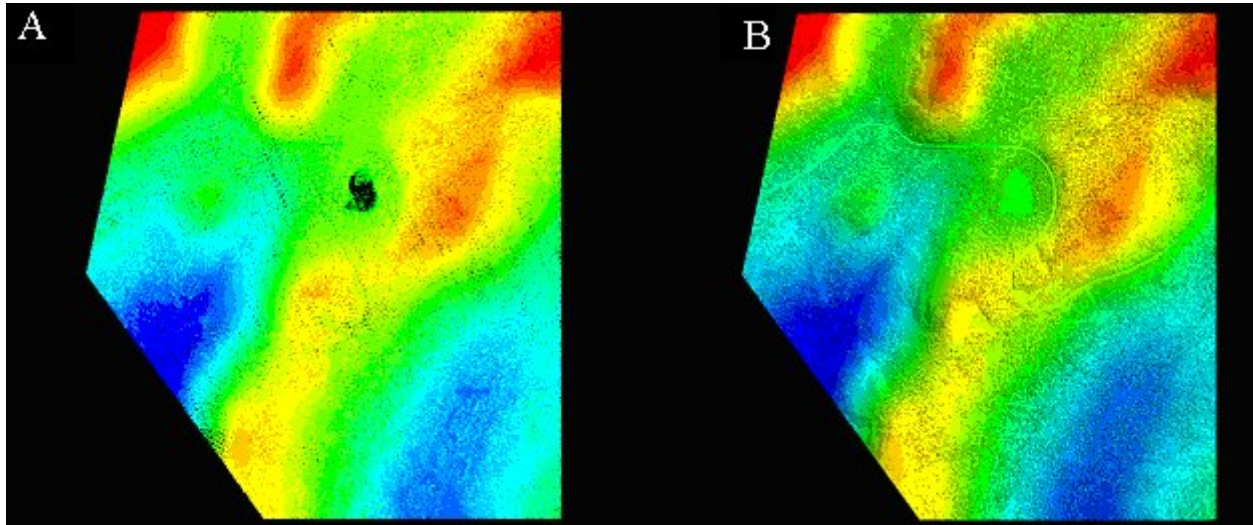


Figure 1. Visualization of LIDAR data. A) As a point cloud. B) As a DEM.

2.1.1. Single Point Selection

An important functionality of visualization software is the one that allows the user to manually do single point selection. This is to navigate through the point cloud using the zoom and rotate controls to pick out single points from the cloud.

2.1.2. Measurements

The ability to precisely select points from the clouds allows the analyst to make measurements such as distances between points, and angles between lines connecting the points.

2.1.3. Primitive Fitting

After selecting a series of points is possible to perform a primitive fitting operation. Primitive fitting is the application of the least square methodology to compute the

spatial parameters that define simple geometric figures or volumes such as lines, circles, planes, spheres, cones and cylinders. Figure 2 illustrate the entire process of primitive fitting starting from the selection of point from the cloud to the fitting of the sphere.

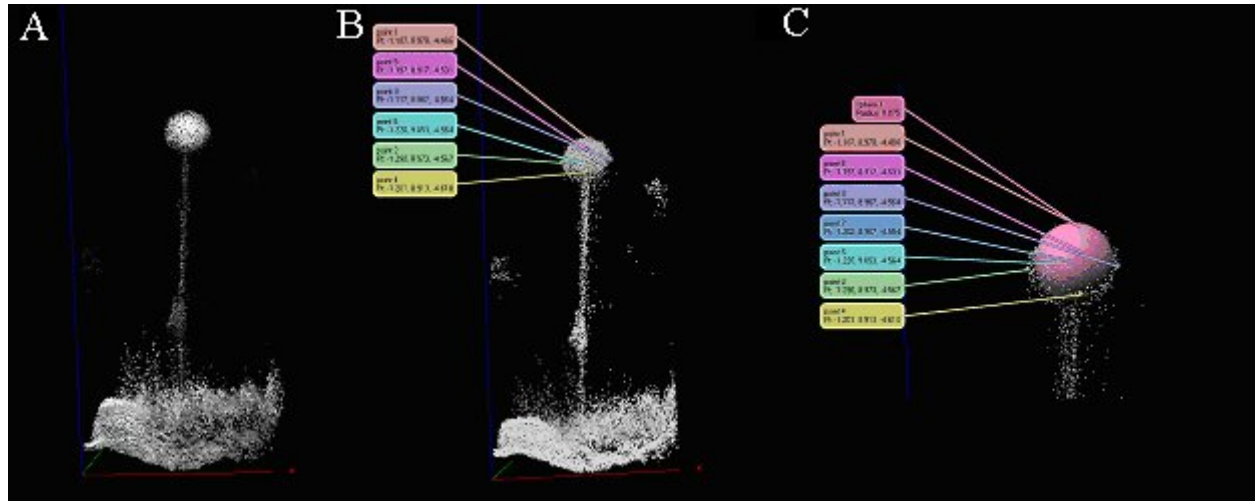


Figure 2. Primitive fitting process illustrated. A) Point cloud. B) Picking points from the sphere surface. C) Fitted sphere based on the picked points.

2.1.4. Generating Cross Sections

Another important visualization tool is the selection of a particular baseline and the generation of a cross sectional view of the point cloud at the baseline as seen in figure 3.

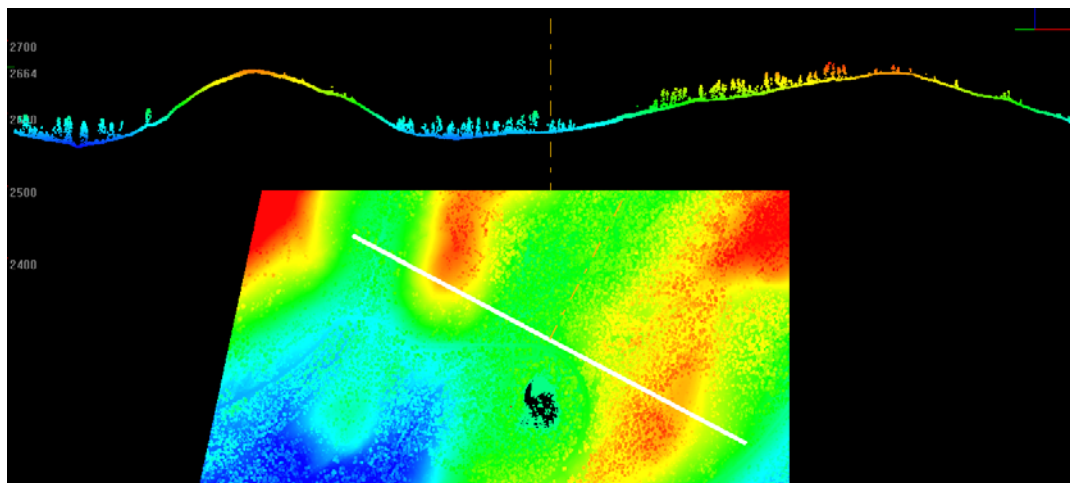


Figure 3. Cross section generation from the point cloud.

2.2. Segmentation, Classification, Filtering

Another important set of operations performed over the point clouds are the ones that allow segmentation, classification and filtering of the points.

2.2.1. Segmentation

Segmentation refers to the operation that will segment or segregate points into different groups based on characteristics without knowledge of what they really are. An example of segmentation could be the separation of points, based on intensity values, into low intensity, medium intensity and high intensity. Under this segmentation scheme points in each group will not necessarily share common spatial characteristics.

2.2.2. Classification

Classification implies the separation of points into different groups or classes defined by an intrinsic or natural characteristic. An example of classification is the separation of the points into vegetation, building or ground classes; each of these groups implies the knowledge of its nature.

2.2.3. Filtering

Filtering is the removal of a set of points from the clouds based on either a segmentation or classification scheme. An example of a segmentation scheme based filter could be the removal of points that are below a certain height value, without considering its nature (i.e. ground or low vegetation). A classification filter could be one that removes vegetation from an urban scene on which only brick and glass is wanted.

2.3. Transformations

There are countless transformations that can be applied to the point clouds, a few of the most frequent are described following:

2.3.1. Rotations and translations

Simple Transformation includes the translation or rotation of the entire point cloud on one or more of the coordinate axes.

2.3.2. Cropping

When an object is scanned there are always points that do not belong to the volume of interest. Cropping allows the creation of a point cloud with only the elements that falls within the 3D space of interest.

2.3.3. Merging

Point Cloud Merging is performed when several point clouds of the same object were collected from different angles or positions each having its own coordinate frame and there is the need to convert all of them into a single spatial coherent point cloud. Merging is performed by setting one point cloud as the base reference frame, and then common points or common primitives are identified between the base and the source point cloud. From the common points a 3D rotation and translation transformation is computed using least squares adjustment. Figure 4 illustrates a merging operation between two point clouds color coded as white and pink that were obtained from different scan angles, using the common points method the pink point cloud was rotated to the white coordinate system to produce a single coherent data set.

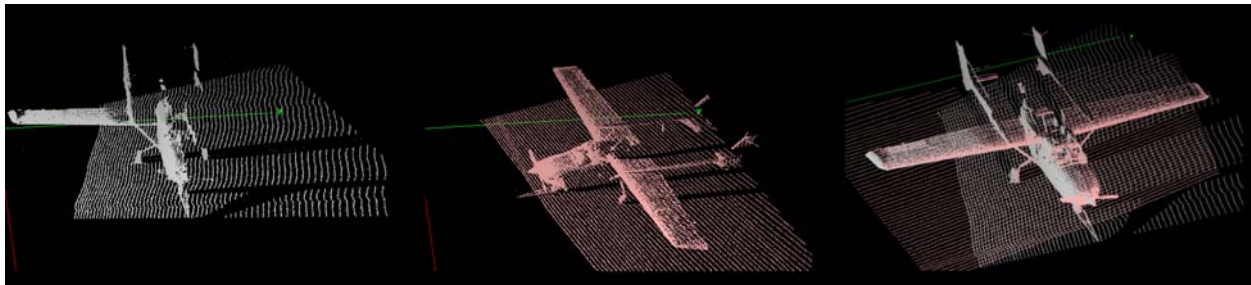


Figure 4. Point cloud merging example.

2.3.4. Geo-referencing

A transformation in which a point cloud with coordinates in arbitrary sensor space is converted into a geodetic coordinate frame is called geo-referencing. Similar to a merging operation, in geo-referencing there has to be a minimum of 3 non-collinear points for which coordinates on both sensor and geodetic frames are known. Based on that set of coordinates the parameters of a 3D rotation and translation transformation are computed. That transformation is then applied to the entire point cloud and as a result the data set is fixed to the specific geodetic frame.

2.4. Gridding

A LIDAR point cloud by nature is an irregularly space data set. The process of converting the point cloud into a regularly spaced data set by means of interpolation is called gridding. Gridding allows the analyst to observe subtle features in the data set. There are many different gridding algorithms the more common are Nearest Neighbor, Inverse Distance Weighting, Triangulation with Linear Interpolation, and Kriging. The regular nature of the grid allows the analyst to perform many mathematical operations such as areas and volumes computations, grid algebra, grid calculus, differentiation, gradients, grid comparison, as well as image processing operations. A complete description on gridding can be found in the GEM report entitled "Basic Gridding of ALSM Point Data" (GEM_Rep_2005_01_003).

http://www.aspl.ece.ufl.edu/reports/GEM_Rep_2005_01_003.pdf

2.5. Advanced Mathematical Operations

The operations discussed so far are commonly performed by the LIDAR analyst using canned algorithms in commercial software packages. However, some applications require advanced or specialized techniques that must be custom programmed in programming languages such as Visual C, Visual Basic or using higher level math tools

such as Matlab or IDL. Examples of these advanced mathematical operations may include the transformations from space to the frequency domain using the Discrete Fourier Transform or with the Discrete Wavelet Transform, the use of spin images to represent objects from a 3D dataset in a single 2D image, and the application of advanced image processing techniques and operations such as edge detection or morphological operations to a gridded dataset.

3. Brief description on selected point cloud processing software.

3.1. *QT Modeler / Quick Terrain Modeler*

Developer:	Applied Imagery / USA
Web Site:	http://www.appliedimagery.com/index.html
Tested Version:	4.0.0 / 6.0
Cost:	
Main Purpose:	3D Visualization of geospatial data.

The Quick Terrain Modeler was developed at Johns Hopkins University's Applied Physics Lab (APL) as a powerful and fast tool for 3D visualization, capable of handling any type of 3-D dataset, generated by LIDAR, Synthetic Aperture Radar (SAR), multi beam sonar, or any other geospatial sensor.

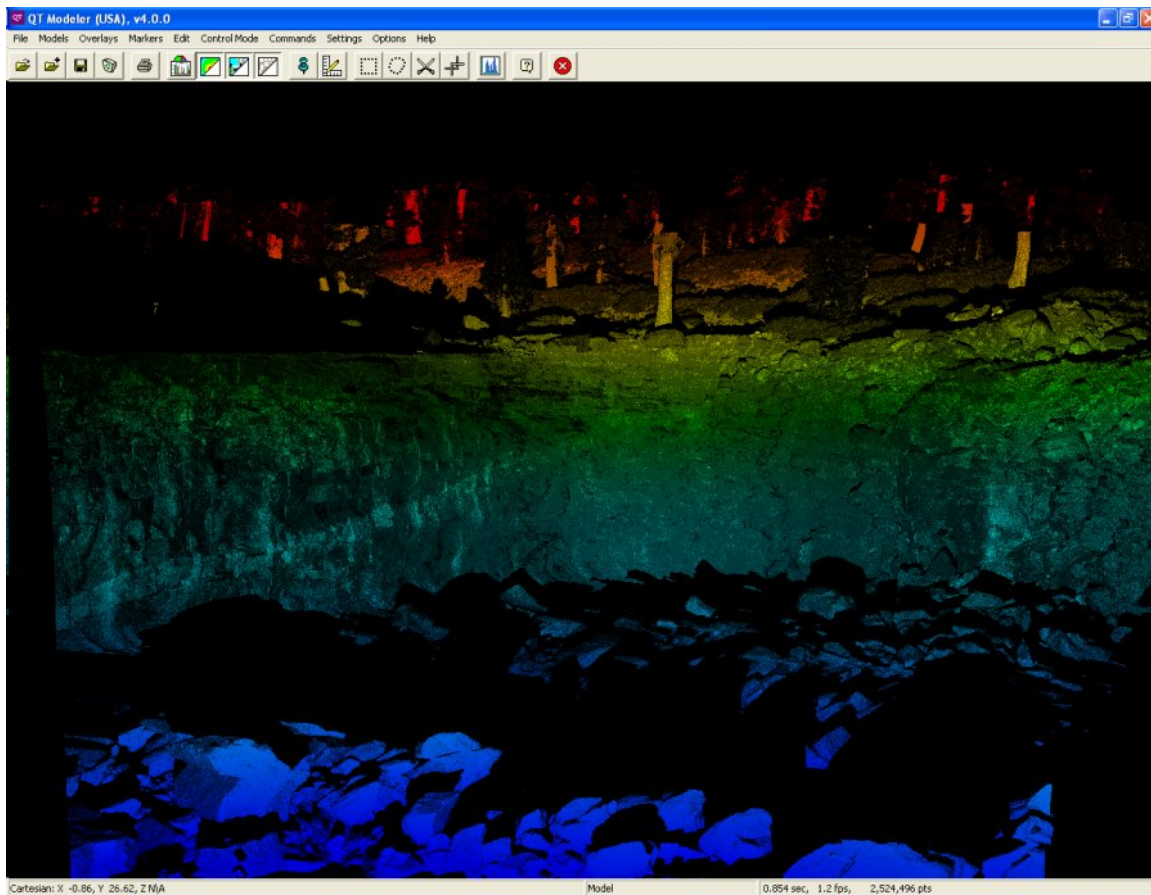


Figure 5. Screen capture of the QT Modeler main window.

QT Modeler work flow starts with the Importing of the LIDAR dataset that can be in the form of generic ASCII XYZ files, the industry standard binary LAS format or one of the QT's proprietary format. From the import data QT builds the point clouds or TIN models which then renders for user visualization. From the graphical interface the user can zoom, rotate and navigate thru the point cloud as well as perform several types of operations to the point cloud or TIN, these can be grouped into Edit, Enhance, Analyze and Export. The Edit functions include cut, crop and smooth features, the Enhance features allows to adjust the illumination and overlay imagery. The Analyze tools allow to simulate flooding, line of sight analysis, height histogram analysis, change detection, slope computation and many more options. Finally the Export tools outputs the point clouds and surface models into a variety of formats that include still images as BMPs, JPGs, GeoTIFF and AVI movie formats.

While testing different software, QT Modeler proved to be by far the best visualization software for point clouds, however it has several limitations with respect to the manipulation and transformation of the dataset.

3.2. Terrasolid Suite

Developer:	Terrasolid Ltd. / Finland
Web Site:	http://www.terrasolid.fi/
Tested Version:	
Cost:	TerraScan: \$ 7,700 Full Suite: \$ 14,700 (terra -scan, -model, -match, -photo)
Main Purpose:	Advanced Manipulation of LIDAR data.

Terrasolid Suite is the most complete, advanced and powerful software available for the manipulation, processing and analysis of LIDAR data. The full suite is composed of 4 main modules: TerraModeler, TerraScan, TerraPhoto and TerraMatch. The Terrasolid

suite is designed to run over Bentley's Microstation CAD software. It therefore has the advantage of working in a CAD environment while processing LIDAR data, providing useful tools such as visualization, adding/placing vectors, labeling, plotting etc. So additional to the Terrasolid License is necessary to obtain a Microstation license.

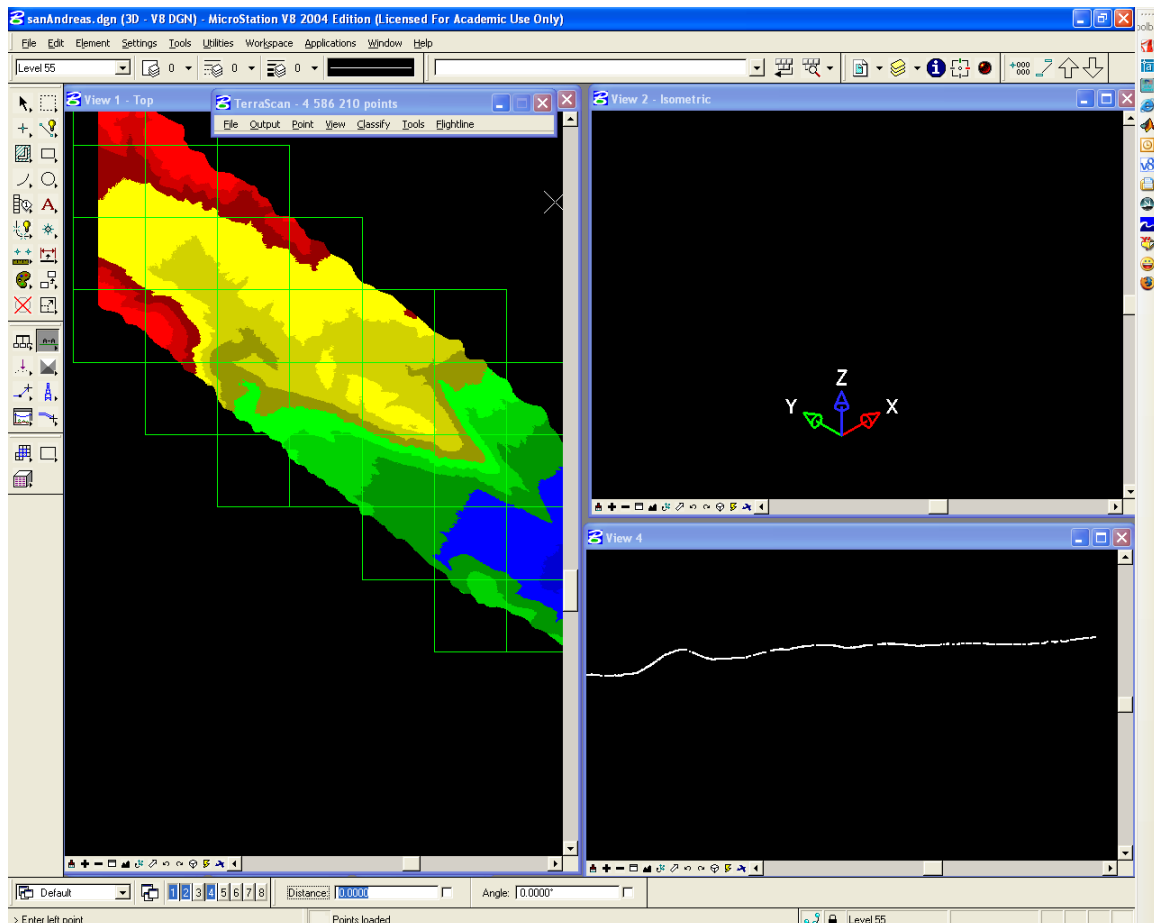


Figure 6. Screen capture of the Terrascan Module running over Microstation.

Terrascan is the lidar point clouds processing software. It comes as an integrated application in Microstation. The application reads points from XYZ text files or binary files. Some of the LIDAR processing functions that can be performed are:

- View the points cloud in a 2D and 3D graphical environment.
- Classify the LIDAR points into default or user defined classes such as ground, vegetation, buildings or wires.

- Classify 3D objects such as towers and buildings interactively.
- Delete unnecessary or erroneous points in a fenced area.
- Remove unnecessary points by thinning.
- Digitize features by snapping onto laser points.
- Automatic detection of powerlines wires or building roofs.
- Export elevation color raster images.
- Project points into profiles.
- Output classified points into text files.
- Coordinate transformation routines.

Terrascan main advantage is the capability of handling big dataset by creating projects and breaking the big dataset into smaller tiles that can be processed independently. The main limitation is relatively poor quality of the point cloud visualization.

Terramodel adds the capability to create terrain models out of the point clouds using triangulation. These models may be used as design aids for constructing 3D elements on the surface, surface visualization, contour generation, profile generation, slope and volume calculations.

Terramatch is used for calibration of laser data and for solving mismatches that might occur between the airborne data under different flight lines. It can be used for solving for misalignments between the inertial measurement unit and the laser scanner. It requires some initial preprocessing in Terrascan.

Terraphoto gives the capability of fusing aerial photography with laser data. It can be used to create orthorectified mosaics using LIDAR data, true orthos, draped models by draping orthorectified images over surface models etc.

3.3. MARS

Developer:	Merrick & Company / USA
Web Site:	http://www.merrick.com/servicelines/gis/mars.aspx
Tested Version:	Mars Viewer 4.0
Cost:	Viewer: Free Explorer: \$6,595 Explorer Pro:\$8,995
Main Purpose:	Visualization and basic processing and analysis.

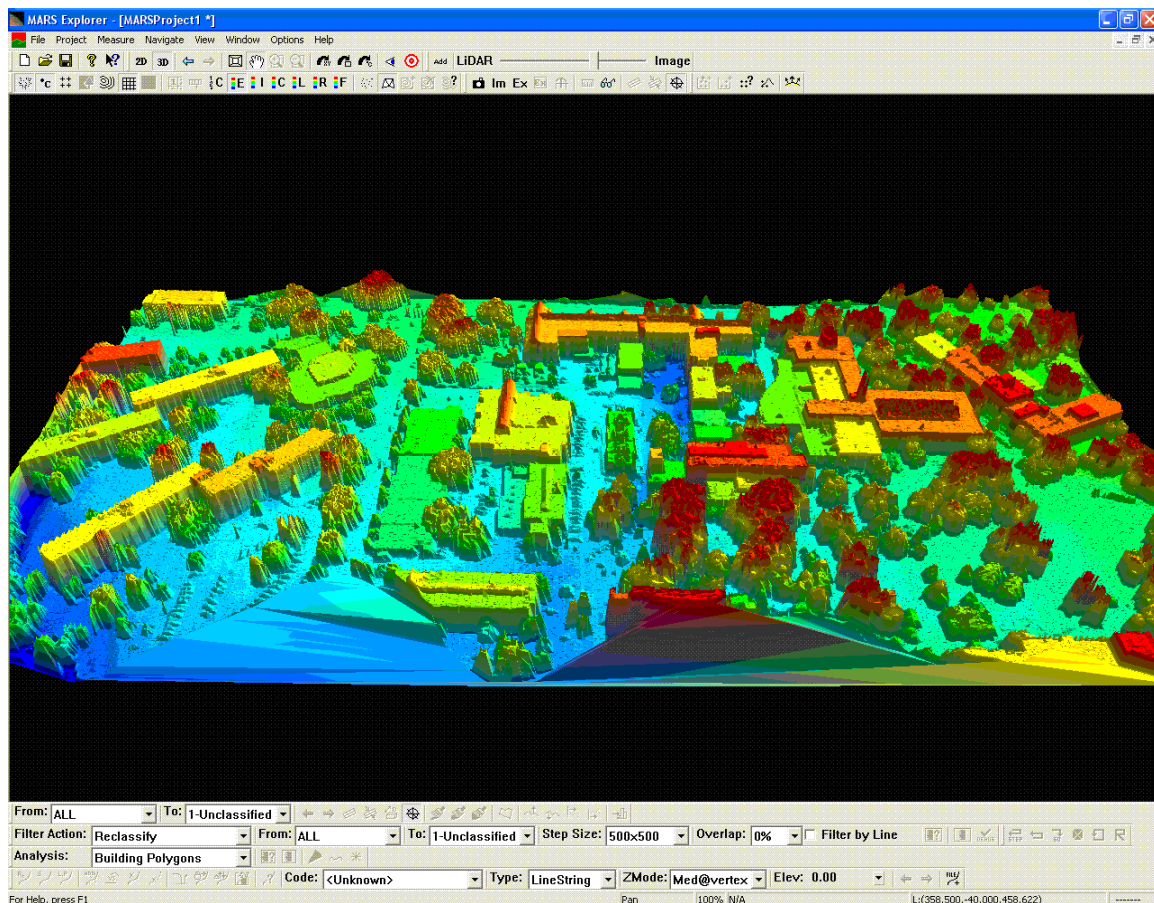


Figure 7. Screen capture of the Mars free viewer.

Three versions of the software are offered: Mars Viewer, Mars Explorer, Mars Explorer Pro. The LIDAR data management is done through the industry standard LAS files. The software reads directly the .las files or ASCII files can be converted to this format through the import tool. The import tools allow to import ASCII files by defining the fields in the text file. The full version has the following capabilities:

- Unlimited data loading capability.
- Instant 2D and 3D, point cloud and TIN rendering.
- Data classification/filtering tools.
- Cross section and profiling tools.
- Import-export functions.
- Imagery background display.
- Imagery fusion with LIDAR.

The filtering options, offered by Mars Explorer version, are located at the lower part of the interface. Some of the filter tools are based on window processing. In this processing is necessary to define a window size on which points are looked for and classified according to some parameter, for example: maximum height point in the window, minimum height point and so on. Also, buffering-based segmentation can be done. These filters options segment out points located at certain distance of other previous classified points or other defined parameter. The free version of the suite, Mars Viewer, looks exactly the same as the more powerful versions, so the user interface does not change; however, the free version only allows us to visualize and import the data (no filtering, no exporting). Nevertheless, the free version is a good tool when you just want to import to .las file, explore and visualize Lidar data.

3.4. *Innovmetric Polyworks*

Developer:	Innovmetric / Canada
Web Site:	http://www.innovmetric.com/Manufacturing/home.aspx
Tested Version:	7.2
Cost:	?
Main Purpose:	Manipulation of LIDAR data for CAD/CAM applications.

Polyworks was created specifically for the manipulation of 3D scanner data used in the automotive and aerospace industry for Computer Aided Design and Manufacturing and reverse engineering. It can be used for the visualization and manipulation of terrestrial LIDAR and small airborne LIDAR data sets.

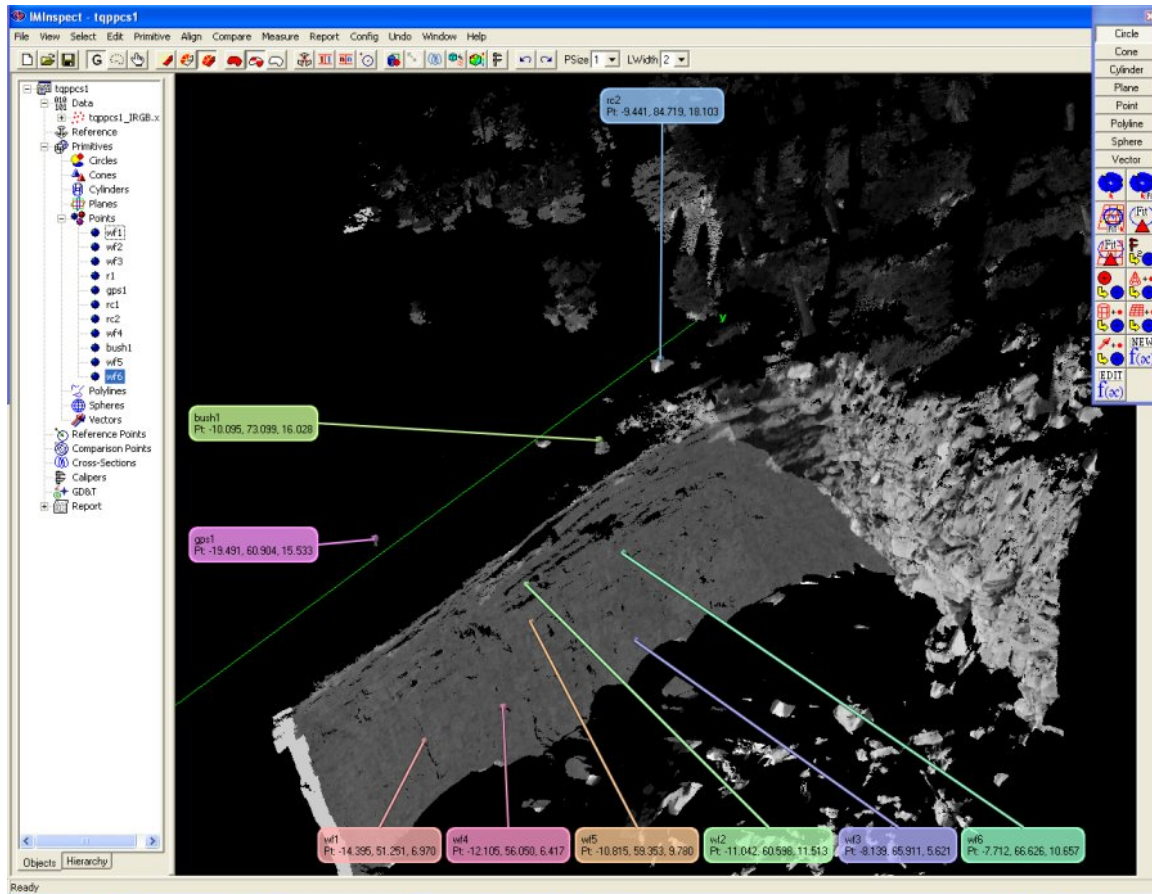


Figure 8. Screen capture of the Polyworks Inspect Module.

Polyworks is modular software composed of IMAlign, IMInspect, IMMerge, IMEdit, IMCompress, IMTexture and IMView. The most useful module is IMInspect which allows visualizing intensity and RGB textured point clouds, select individual points from the point clouds and fit primitives (points, vectors, circle, cone, cylinders, planes, polylines, spheres and Vectors) to the selected points. It allows to convert the point clouds into surface models using the primitives. It can also merge scans taken from

different platforms and geometries into a single data set. The main advantage is the ease and accuracy to navigate thru the point cloud and select individual points.

3.5. *Fledermaus*

Developer:	Interactive Visualization Systems / Canada
Web Site:	http://www.ivs3d.com/
Tested Version:	6.50a Professional
Cost:	
Main Purpose:	Visualization of 3D geospatial data

Fledermaus is a powerful interactive 3D data visualization system that is used for a variety of applications and visualization of remotely sensed data. Innovative data exploration features including the ShiftScape™ rendering engine and the Bat (3D input device), allow for intuitive 3D exploration of geo-spatial data. A wide variety of industry standard formats are supported for direct import of data to the 3D scene. Object types such as digital terrain maps, point clouds, lines, polygons, satellite imagery, etc. can all be loaded and analyzed in a single scene. Due to its flexible object oriented software design, Fledermaus can be easily tailored to support many additional visualization modules. Its major features include :

- Multiple data sets and types of different resolution can be visualized and interactively explored at the same time.
- Integrated support for very large data sets.
- On the fly profile line extraction
- All data sets can be geo-referenced in the 3D scene.
- Users can interactively query data sets to select coordinates for profiles and measurements.
- Advanced object oriented architecture allows easy integration of new data types into the system.

- Explorations can be recorded and used to create movies of data exploration sessions.
- Visualizations can be displayed in 3D stereo with suitable graphics hardware.
- Software and data files can be used across wide variety of computer platforms from laptops to large immersive visualization systems.

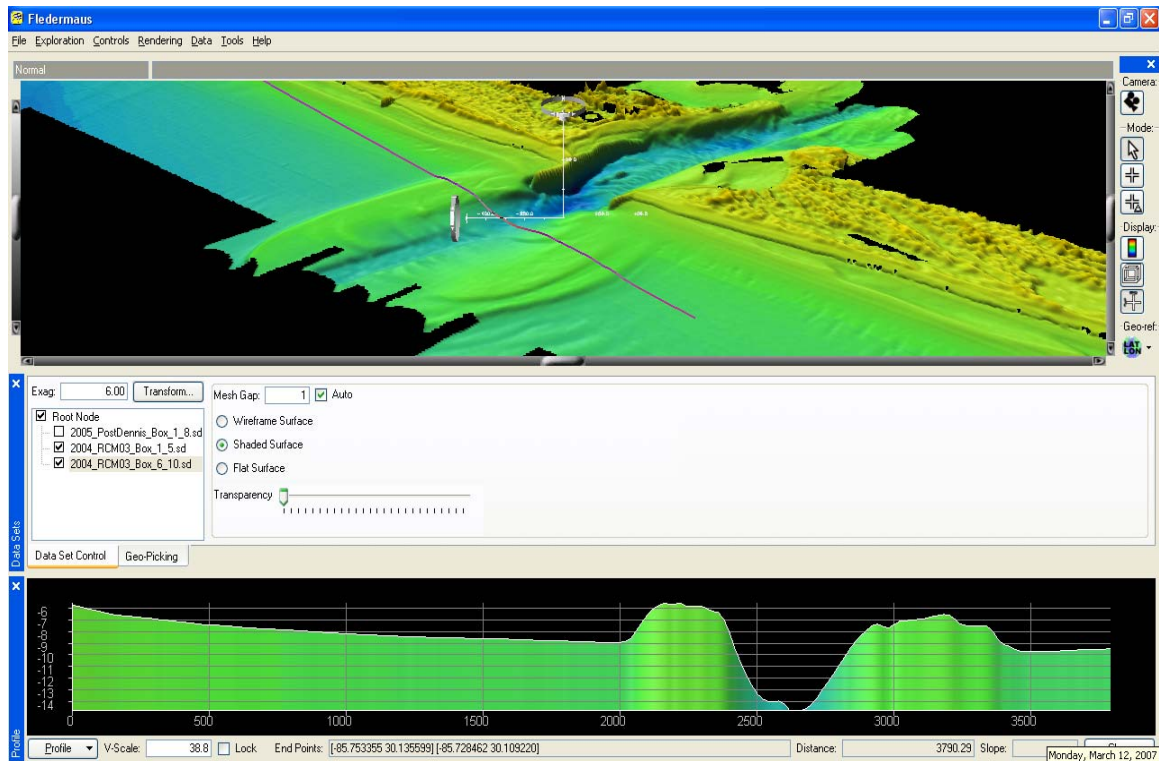


Figure 9. Screen capture of Fledermauss displaying Bathymetric LIDAR data.

Main advantage of this software is its exceptional visualization capabilities including its unique ability to do 3-D split screen stereo visualization of the data. Major disadvantage is that it provides limited tools for data analysis and gridding, however, it does provide added flexibility to import GRIDs generated from external packages such as SURFER.

3.6. *Matlab*

Developer:	MathWorks / United States
Web Site:	http://www.mathworks.com/
Tested Version:	7.0
Cost:	\$1000 academic version of full suite.
Main Purpose:	High-level language for technical computing.

Although not designed specifically as a LIDAR dataset handling software, MATLAB is a high-level technical computing language that enables LIDAR data algorithm development, data visualization, data analysis, and numeric computation. Some of the LIDAR data analysis tools that can be developed include:

- Point cloud plotting.
- Point cloud gridding.
- Point cloud segmentation, classification and filtering.
- Detection algorithm development.
- Dataset spatial frequency analysis.

For more information of Matlab functions used to plot LIDAR data please refer to the GEM report entitled “Useful Matlab Plotting of Topography and ancillary data” (Rep_2004-12-001). http://www.aspl.ece.ufl.edu/reports/Rep_2004-12-001.pdf

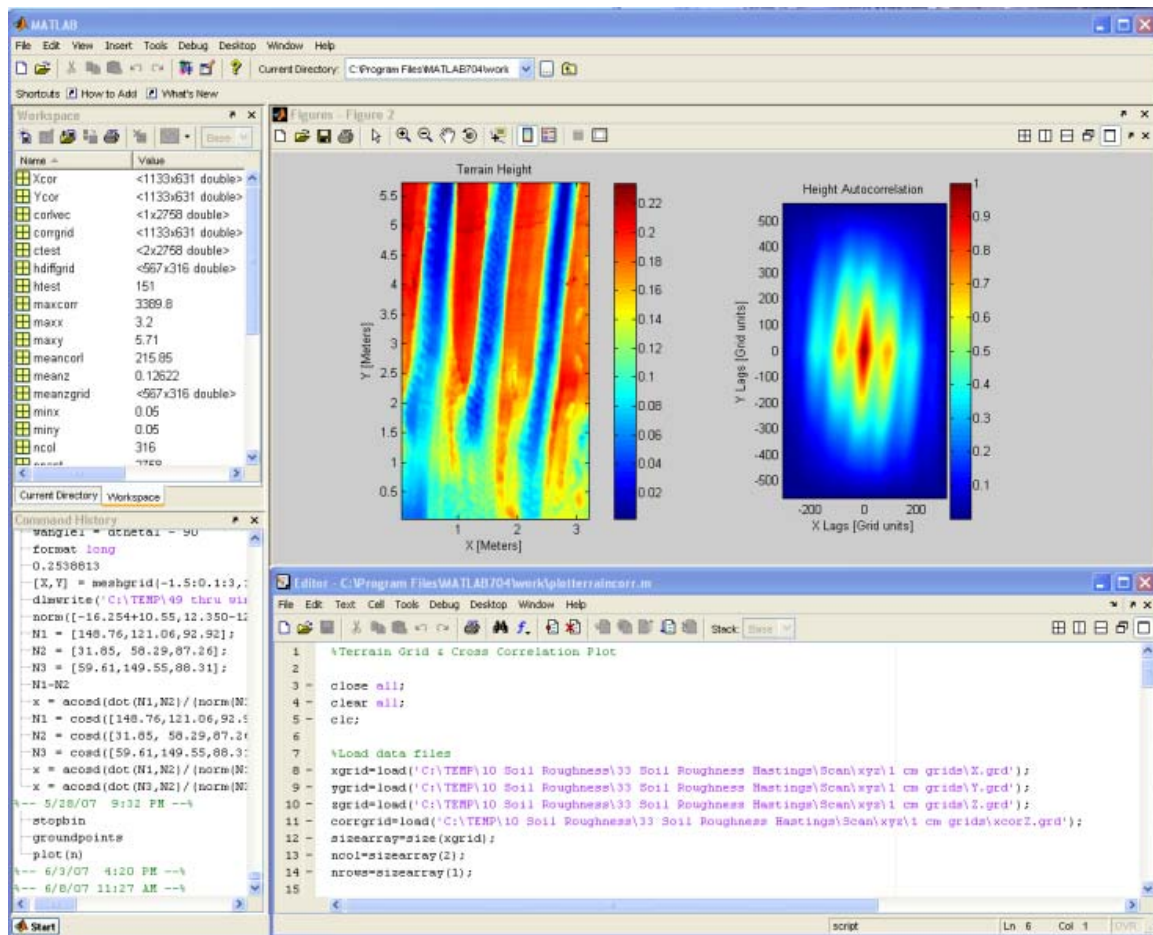


Figure 10. Screen capture of Matlab displaying a routine used to compute and plot gridded LIDAR data and a 2D autocorrelation function.

3.7. *LViz*

Developer:	Jeffrey Conner, Active Tectonics Research Group Arizona State University /USA
Web Site:	http://lidar.asu.edu/LViz.html
Tested Version:	1.2.0
Cost:	Free
Main Purpose:	Visualization of LIDAR data.

Designed for 3D visualization of LIDAR / ALSM point and interpolated data, the tool offers import of LIDAR point cloud data (delimited text file) or interpolated surfaces (in

ascii or arc ascii grid formats). LViz also offers texture mapping and user control over display settings such as data and background color.

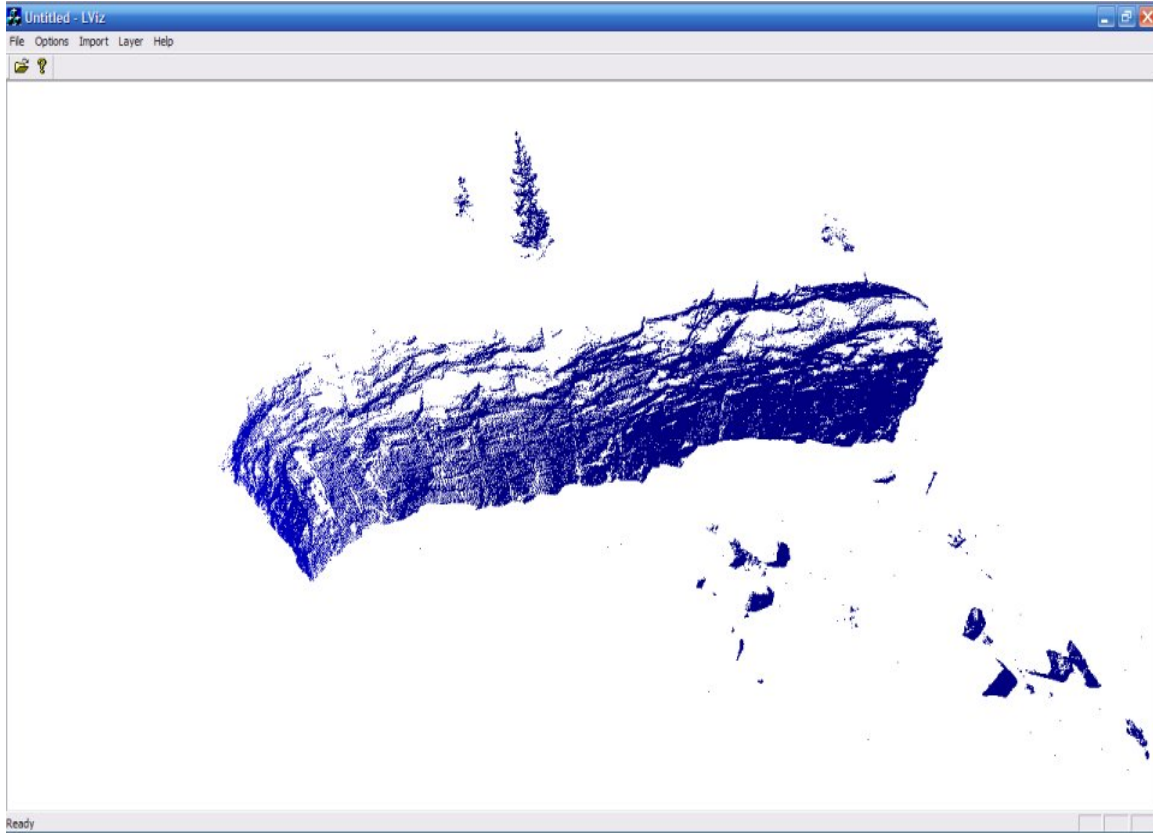


Figure 11. Screen capture of ASU's LViz LIDAR data visualization software.

3.8. *Surfer*

Developer:	Golden Software
Web Site:	http://www.goldensoftware.com/products/surfer/surfer.shtml
Tested Version:	8.06
Cost:	\$ 599
Main Purpose:	Creation, analysis and visualization of geospatial regular grid datasets from irregular spaced datasets.

Surfer is a complete software specializing in the generation, analysis and visualization of regular grids of geospatial information. It can import data in a variety of formats including Excel, Lotus, ASCII text and Surfer data files. From the data grids and

variograms can be created. Available gridding methods include inverse distance, Kriging, minimum curvature, modified Shepard's, natural neighbor, nearest neighbor, polynomial regression, radial basis functions, triangulation with linear interpolation, local polynomial and moving average. After the grid has been created, Surfer can plot it as contour, surface, wireframe, vector, image, shaded relief, and post maps. Virtually all aspects of the maps can be customized to produce exactly the desired presentation. The embedded tools and algorithms allow the user to perform a variety of grid operations including grid algebra, calculus, volume and area computations, extractions and transformations.

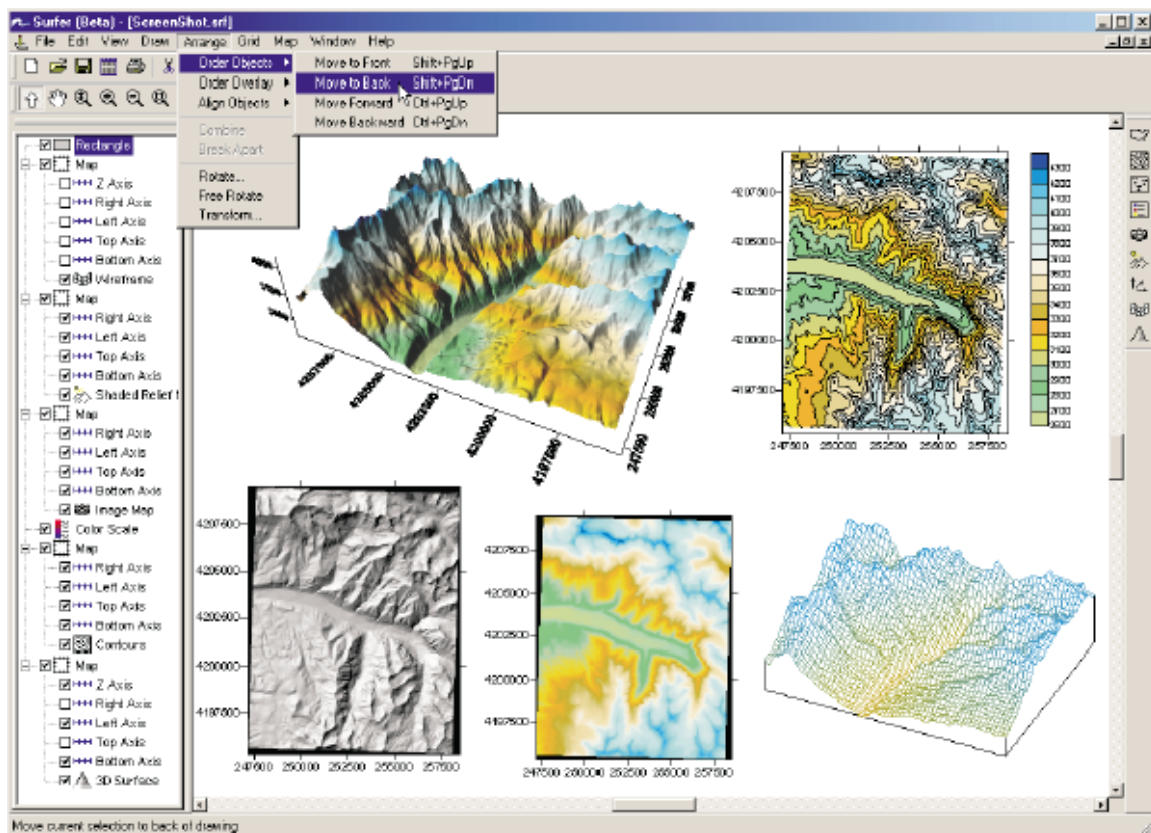


Figure 12. Screen capture Surfer regular geospatial grids visualization and manipulation software.

3.9. Other Software worth mentioning.

It is impossible to describe all the software on the market that is designed or has the capabilities to process LIDAR data. The focus of this report is to provide a description of the most common referred software that cover the processing workflow end to end from visualization to grid model creation and manipulation. However, there are a couple of applications that were not tested for this report but we have knowledge that are widely used and may turn to be interesting for our reader. Among these software is worth to mention:

3.9.1. NOAA Data Handler

Developed by NOAA to process their coastal topographic LIDAR data, Data Handler is an extension to ArcView or ArcMap. It enables the analysis of LIDAR data within a Geographic Information System (GIS). Users must have the Spatial Analyst to run this extension. Data Handler is available for public download from:

http://www.csc.noaa.gov/crs/tcm/lidar_handler.html

3.9.2. LIDAR Analyst for ArcGIS

Originally developed by Visual Learning Systems, Inc. is now marketed by Leica Geosystems. LIDAR Analyst is an extension for ArcGIS that enables loading, editing, visualizing and extracting information from LIDAR data. Its main features are : bare Earth extractor, building extractor, tree and forest extractor and point cloud clean-up tools. More information on LIDAR Analyst is available at:

<http://gi.leica-geosystems.com/LGISub1x286x0.aspx>

3.9.3. IDL

Interactive Data Language or IDL for short is a software developed by ITT Visual Information Systems, Inc.. IDL has a vast collection of functions and routines, from which the user can generate its own code to access, analysis and visualize LIDAR data.

IDL is used extensively in government research laboratories and agencies such as NASA and NOAA.

More information on IDL can be found at:

<http://www.itvis.com/idl/> .

4. Comparison table on the capabilities of the selected point cloud processing software.

	QT Modeler	Terrasolid Suite	MARS	Innovmetric Polyworks	Fledermaus	Matlab	LViz	Surfer
Visualization								
Simple Point Display	✓	✓	✓	✓	✓	✓	✓	
TIN/DEM Display	✓	✓	✓		✓		✓	✓
Intensity Textured Point Cloud	✓	✓	✓	✓	✓			
RGB Textured Point Clouds	✓	✓		✓	✓			
Color Coding	✓	✓	✓	✓	✓	✓		
Image Rendering	✓	✓	✓	✓	✓	✓	✓	✓
Video Rendering	✓			✓	✓	✓		
Zoom/Rotate/Navigate	✓	✓	✓	✓	✓	✓	✓	✓
Profile Generation	✓	✓	✓	✓	✓	✓		✓
Measurements	✓	✓	✓	✓	✓			✓
Segmentation	✓	✓	✓	✓		✓		
Classification	✓	✓	✓			✓		
Filtering	✓	✓	✓			✓		
Transformations								
Point Cloud Rotation	✓	✓		✓		✓		
Cropping	✓	✓				✓		
Scan Merging	✓	✓		✓		✓		
Point Selection				✓				
Primitive Fitting				✓		✓		
Datum/Projections Conversions	✓	✓				✓		
Geo-referencing	✓	✓		✓		✓		
Gridding								✓
Advanced Operations		✓				✓		✓