SPATIAL SYSTEMS ASSOCIATES, INC.
GIS & FMIS IMPLEMENTATION & SUPPORT SERVICES
GEOGRAPHIC INFORMATION SYSTEMS | FACILITIES MANAGEMENT INFORMATION SYSTEMS

# DERIVATION OF CONTOURS FROM LiDAR DATA

Since GIS technology began to become popularly utilized in the early 1990's, a number of layers or themes of data have become commonly requested when a new GIS system is deployed. Some of these layers are known as "base" map layers, i.e. layers upon which other data is built. Examples of base map layers include digital orthophotography and planimetric data.

There are a number of other layers that are commonly requested by users of GIS systems, whether the users are planning, public works, assessment, emergency management, and other government offices. These layers include **street centerline** (topologically built and maintained with address ranges) for routing; a **cadastral** layer depicting the boundaries of property ownership (tied to ownership, address, and assessment data files); and **elevation** data.

## Elevation Data

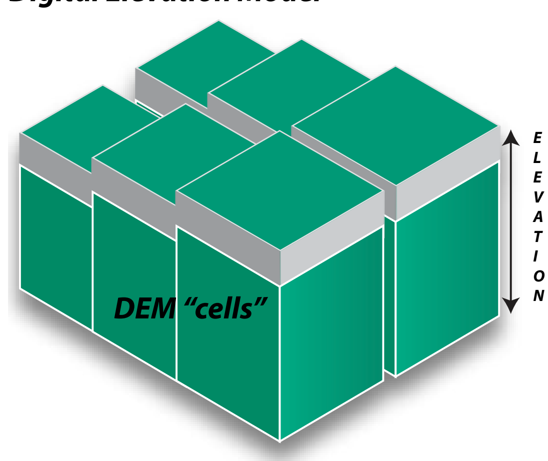
Elevation data is an important layer of information to have in a GIS in that it is necessary to understand land slope characteristics, water flow characteristics, line of sight characteristics for placement of antennas, planning an urban landscape, and other uses.

Until very recently, the most common visual representation of terrain has been in the form of contours. Contours are vector lines representing a constant elevation, attributed and annotated with that elevation. Contours are generated at constant intervals—normally two foot, five foot, ten foot or twenty foot. The interval selected is often determined by the steepness of the terrain. One foot or two foot contours in mountainous regions displayed at normal mapscales result in a very dense set of lines, often indiscernible from one another. Ten foot contours in flat terrain are spaced too far apart. Each successive contour line differs in elevation by the amount of the interval level, and according to generally accepted standards, the elevation of the location on the ground overlaid with a particular contour line is "guaranteed" to be within ½ contour interval of what would be determined by first order survey techniques at that location. In the past, contours have been generated photogrammetrically and often were produced along with planimetric data.

Individuals accustomed to viewing contour maps can easily visualize the steepness of the terrain (a function of the closeness of the contour lines to one another) and the direction of slope (perpendicular at any point to the direction of the contour line). The direction of slope is effectively the direction that water would flow when poured on the ground at that location.

Just as recent advances in computer technology have made the use of higher resolution imagery plausible, these advances have made alternative representations of elevation data possible. These representations are known as Digital Terrain Models (DTMs) and include Digital Elevation Models (DEMs) and Triangulated Irregular Networks (TINs). DEMs are "raster" representations of elevation, in which each "cell" in the DEM represents a specific area on the ground that is assumed to have a constant elevation. Just as the resolution of imagery is expressed in the size of an individual pixel of the image, a DEM has a "resolution" that is the area on the ground that each cell represents. DEMs are available on a global basis at a resolution of 30 meters resulting from data collected by the space shuttle a couple of years ago. DEMs are available on a national level at a resolution of 10 meters. Locally, DEMs may be available at much higher resolutions. As with imagery, the size of the dataset is proportional to the square of the resolution of the data. Check the metadata carefully to determine the accuracy to which a DEM has been developed since there is no standard based on cell size.

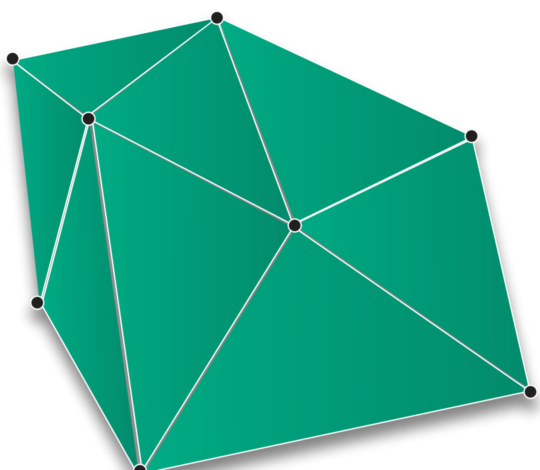
***Digital Elevation Model***



## Derivation of Contours from LiDAR Data

When DEMs are displayed on a computer screen or a picture the individual cells are not discernible. Color is often applied in shades with each color representing a specific elevation. The resulting image allows for intuitive understanding of the terrain, much like someone who is accustomed to viewing contours can envision terrain from a contour map.

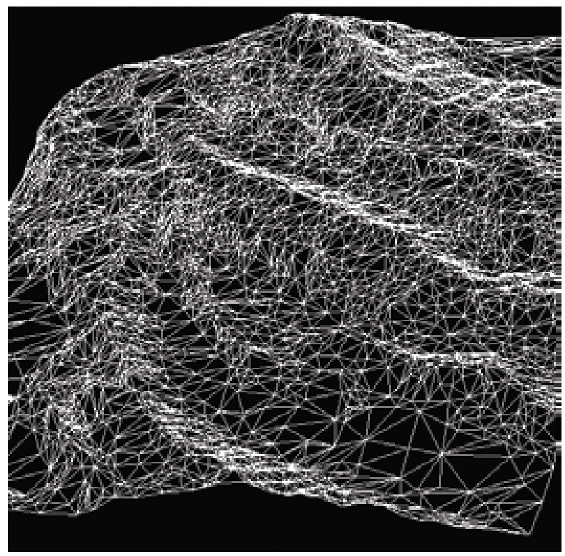
TINs are an alternative representation of the surface of the earth. TINs are, as the name implies, made up of irregular triangles that are tied together along the sides of the triangle to form a continuous surface.

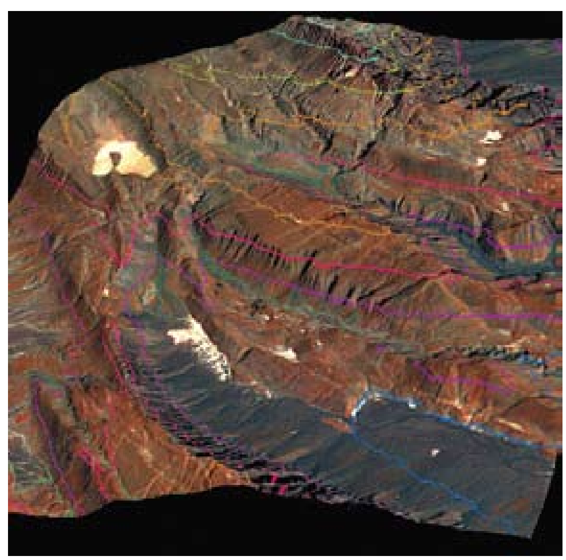


***Triangulated Irregular Network***

The terrain of an area can be visualized, utilizing a TIN in much the same way as a DEM, except that the surface is composed of thousands of triangular surfaces, rather then square cells.

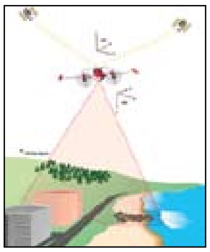
These surfaces can then be colored to simulate terrain coloration, and a graphic can be displayed that is intuitive to evaluate. Triangles in the TIN are formed from a series of points with known elevations, most often randomly spaced. These points can come from a variety of sources. When the accuracy of the points is known, the resulting TIN can be used for a variety of analytical purposes with confidence.





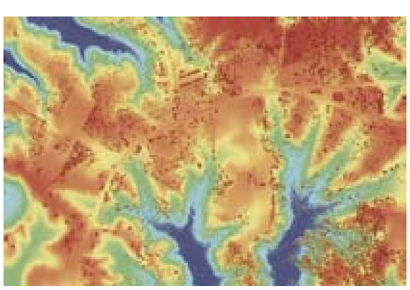
### LiDAR Data

One of the most common sources of this point elevation data today is from a technology known as LiDAR—Light Detection And Ranging. LiDAR technology utilizes airborne lasers and detectors. Small aircraft are outfitted with GPS and inertial guidance technology similar to that used by the military in missile targeting and guidance. This technology accurately tracks the location and elevation of the aircraft as it collects data. The laser in the plane fires a stream of light to the ground, known as pulses, normally at frequencies of 25-100 khz (i.e. 25,000 to 100,000 pulses per second). As each pulse of light travels down from the plane, it is reflected by whatever it hits—rain drops, trees, buildings, or the ground itself. Sensors on the plane measure the amount of time it takes for that pulse of light to be reflected and return to the plane. Knowing the location and elevation of the plane, the speed light travels, the direction the laser was pointing when fired, and the time from the emitting of the pulse to the return, the distance to the reflecting object at a specific location can be determined.



*Courtesy of Optech, Inc.*

Several "returns" from a single pulse can be detected. If an individual is interested in the tops of trees, the first return data is most useful. Ground elevation data is derived from the last return. Even then, if the light pulse strikes the top of trees and doesn't penetrate further, or strikes the top of a structure, the last return is not the bare ground. A postprocess must be performed to remove these "artifacts" from the last return data to derive a set of "bare earth mass points" that is often one of the deliverable products from LiDAR collection. Elevation data can be collected over large areas very cost effectively utilizing LiDAR technology—typically less than $1 per acre to collect, process, and QC the data—and normally results in points on the ground averaging 0.5–2 meters on center. These collection and processing efforts result in very large amounts of data.



***Example of LiDAR data***

LiDAR data must usually meet standards established by the Federal Emergency Management Agency (FEMA) for accuracy if it is to be used in the derivation of Digital Flood Insurance Rate Maps (DFIRMs). FEMA criteria requires that a set of quality control (QC) points be collected—20 in each of five land use categories—utilizing first order survey techniques. A TIN is then derived from the bare earth mass points described above, and at each location of the field collected QC data, the elevation difference between the TIN surface at that location and the surveyed elevation is calculated. For 95% of the points, the Root Mean Square Error (RSME) must be less than 18.5cm (7.28 inches) to meet FEMA requirements. Often the QC process results in much better accuracy. It is not unusual for the QC process to demonstrate accuracy of 7-12 cm (2.75 – 4.72 inches).

A second common deliverable in a LiDAR project is a DEM derived from the bare earth mass point file. DEMs are useful in that they always represent a structured grid or "raster" elevation model over which imagery can be conveniently draped by several software packages, however note that DEMs derived from LiDAR or Contour data are derivative products, and therefore not as accurate as the source information except at points common to both datasets.

## Contours from LiDAR Data

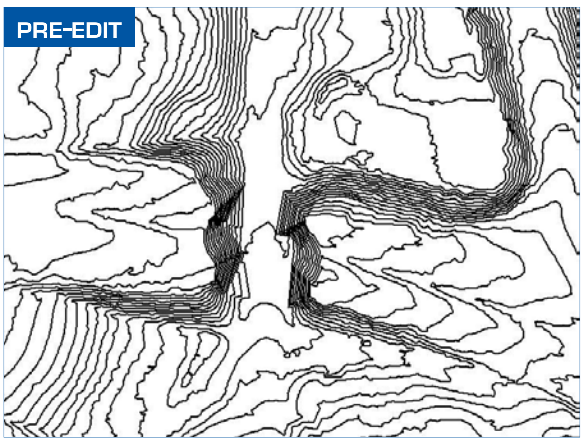
While the TIN generated from bare earth mass points is the most accurate surface representation of LiDAR data, many engineers, planners, and others are much more accustomed to viewing elevation data in the form of contours and contour maps, as described earlier. The generation of visually acceptable contours from LiDAR data is now a practical process though it is not automatic.

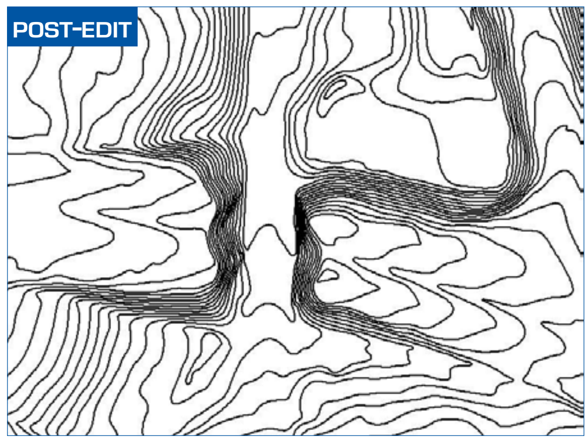
LiDAR bare earth mass points are the only locations on the ground derived directly from the returned light pulse in LiDAR collection. Automated generation of contours from a file of arbitrary points is possible, however the resulting contours are not visually pleasing—i.e. not what the user is accustomed to seeing in contours generated utilizing photogrammetric processes. However, while photogrammetric contour development is as much an art as science, automated contour generation from LiDAR mass points is purely analytical.

## Derivation of Contours from LiDAR Data

Given a known accuracy of the LiDAR dataset, one can arguably generate contours that meet the ½ contour accuracy specification. For example, if the QC process for LiDAR described in the preceding page results in a RMSE of less than 6 inches (15 cm), it is reasonable to assume that 1 foot contours can be generated that meet national map accuracy standards for contours (2x the RMSE). Since LiDAR data that meets FEMA specifications must be below a RMSE of 18.5cm, it is reasonable to generate 2-foot contours with confidence from this data.

As noted earlier, contours can be generated automatically from LiDAR bare earth mass points or TINs, however the resulting contour lines, while accurate, are not visually appealing. The following examples demonstrate 2-foot contours automatically generated from LiDAR mass point data in Maryland alongside a smoothed version of the same data:





Since contours are frequently used as an overlay on orthophoto images or planimetric data to convey a sense of the topography of a region, availability of smoothed contour linework is important. However, there are no automated tools available to provide this smoothing. While certain tools are available to apply splining algorithms to linework to smooth out abrupt changes, such algorithms do not check to insure that the resulting linework does not violate the ½ contour interval rule—that is, the algorithms may produce artistic linework that no longer meets national map accuracy requirements. Spatial Systems Associates (SSA) has been producing LiDAR data—including management of the acquisition, postprocessing, QA/QC, and production of final workproduct—for state and county agencies in the mid-Atlantic for approximately five years. All of the workproduct has been demonstrated to meet FEMA accuracy requirements. SSA has also generated contour data for counties in Maryland from this LiDAR workproduct. We have developed tools and techniques that produce a visually acceptable contour product while respecting the rules required to assure that we continue to meet national map accuracy standards for the final linework.

## Contour Creation Process

The contour production process developed by SSA involves generating contours with the use of TINs and a series of routines developed for use in the ESRI ArcGIS environment. The LiDAR data is typically cut to a specified indexing scheme agreed upon between the contractor and client. SSA creates a TIN for each index tile used in the LiDAR collection process and includes all bare earth mass points within that index. In addition to the mass points inside of each index tile, all mass points contained within a predefined buffer distance surrounding the index are included in the TIN production. These surrounding mass points are included to prevent a hard elevation drop-off or distinct edge at the tile boundary. By including the additional data, the contours to be created will have seamless transition from tile to tile. In addition to the mass points, features such as bridge decks, river channels, and large water bodies including ponds, lakes, and reservoirs are also incorporated into the TIN creation process. These features are included to represent any known change in surface continuity. The water features in particular are assigned elevations, derived from LiDAR mass points, which maintain a given elevation for ponds and lakes and ensure downhill flow for rivers. Once the TIN has been created, the contours can be generated.

With the TIN representing the elevation source, 1-foot contour lines are extracted using standard applications in the ESRI ArcGIS environment. There are draw-backs to using the standardized tools provided by many software packages, particularly the very jagged lines that can be seen in **Figure 1**. In addition to the jagged lines, standard applications produce many miniscule self- enclosed lines representing minor changes in elevation. This is in fact a true representation of the ground. It does, however, lead to a cluttering effect that may adversely affect the interpretation of the contour lines. From a strictly cartographic (artistic) perspective this data has to be "massaged" to approximate the generalized lines representing a constant elevation similar to contours developed photogrammetrically. SSA has developed routines to directly address these issues.

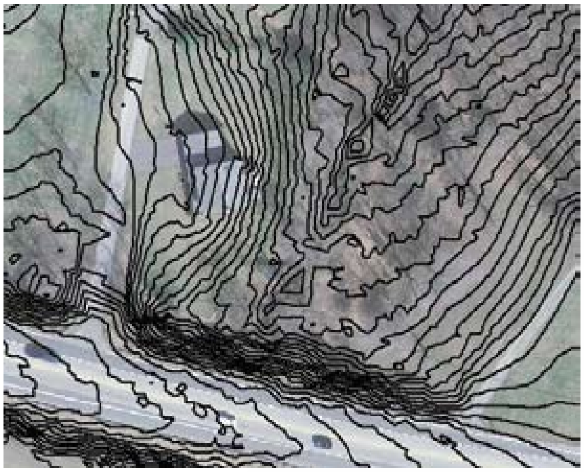


***Figure 1—Automatically generated 1 foot contours***

# Derivation of Contours from LiDAR Data

***Figure 2—Automatically generated 2 foot contours***

Generally, 2-foot, 4-foot, 5-foot or 10-foot contours are the standard required deliverable. In order to insure that the ½ contour specification is not violated, it is necessary to generate initial contours representing the ½ final contour interval. For example if 10-foot contours are the final deliverable, 5-foot contours would be generated in the initial contour development. Often, 2-foot contour intervals are required. In this case, SSA creates 1-foot contours in the initial process to retain the standard of the contour line not violating ½ of a contour interval. By generating 1-foot contours the possibility of the 2-foot contour lines breaching the 1-foot contour lines threshold is greatly reduced. Though accurate, providing contour lines as shown in **Figure 2** would not meet the cartographic standards that most users of contours have come to expect. The jagged lines are not cartographically (artistically) pleasing. To improve upon this, SSA has generated a routine to "smooth" the contour lines while holding the accuracy of the data true to the plus or minus ½ contour interval specification.

Once the 2-foot contour lines have been generated, a routine is run to remove the thousands of minute self enclosed loops and reduce the jagged edges that are created when using standard contour creation applications. It is not uncommon to have self enclosed polygons represented on a contour map—they typically indicate a hill or depression. The question is, how small of a hill or depression should be shown? To address this, SSA has developed a technique to limit the number of these self-enclosed

***Figure 3—First smoothing routine***

contours by setting a minimum perimeter length threshold of the overall polygon line—this effectively removes polygon contour lines smaller than this predefined distance. In addition to resolving the self enclosed lines, the routine also addresses the jaggedness of the contour lines. SSA's intent is to reduce the "noise" shown above in **Figure 2** and create a smoother contour line that remains true to the ½ contour interval rule, while producing results similar to photogrammetrically generated contours. As shown in **Figure 3** the output of this routine has improved upon the initial product displaying less jagged contour lines, however sharp edges are still present. It is necessary to run a final routine that will further "smooth" these contour lines.

***Figure 4—Final product***

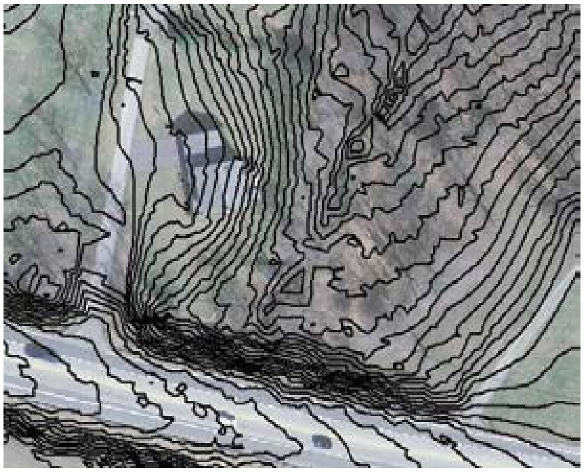


*Figure 1—Before linework smoothing*

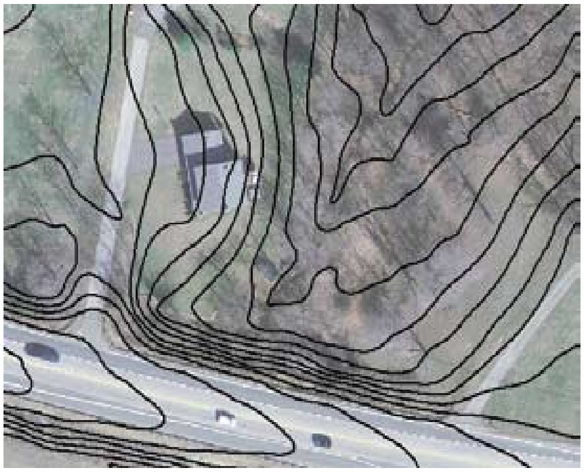


*Figure 4—After linework smoothing*

This process is similar to a typical splining algorithm traditionally used to develop contour lines, however it insures that the resulting linework remain within the boundaries established by the ½ contour interval data. By incorporating this into the routine, we balance cartography and accuracy. Through the series of routines run, the final output is a set of smooth, accurate contour lines as shown in **Figure 4**. The analytical methods that SSA has developed to create contours continue to meet the national map accuracy standards for contour mapping.

The contour production process does not end once the routines have been completed. Following the contour creation process, the contour lines are run through a rigorous QC session. Every line segment is reviewed by on-site analysts to inspect for cartographic errors generated throughout contour production. These errors can include but are not limited to self intersecting loops, sharp points or angles in the lines, and intersecting or crossing contour lines. This QC process involves two different analysts reviewing the contours. In this process one analyst will progress through a given index tile flagging areas of concern. At the completion of this review the second analyst will review the flagged areas making the necessary changes to the contours. On average, an area covering approximately 300,000 acres will require somewhere in the neighborhood 1,500 hours of hands on QC. By taking this meticulous approach, SSA is very confident that the final contour product meets all general purpose contour mapping standards.

While the resulting contour linework from this process meets national map accuracy standards, keep in mind that any derivative product is necessarily less representative of the collected data than the data itself—interpretations and approximations must be made to develop either DEM or contour dataproducts from bare earth mass points. These derivative data products should primarily be used for display purposes. Any analytical work that is performed—modeling, etc—should use the LiDAR bare earth mass points and a resulting TIN as the surface on which the analysis is performed. Further, bear in mind that the bare earth mass points are only representative of what the laser can see from the air. Culverts under roadways, bridges, and other underground conveyances of water are not evident in the mass point file. In order to properly model stormwater flows, it is therefore necessary to first capture and then integrate into the model these features. Since today's hydrology tools do not model depressions in the terrain into which water will flow forming puddles until the depression is full, it is necessary to modify the surfaces to eliminate the depressions in order to assure positive flow of water.

All datasets produced should include standardized metadata files. When dealing with elevation dataproducts, this metadata is especially important to pay attention to. Not only does it include information about the source date and accuracy of the data, it includes information about horizontal and vertical datums to which the data is referred. The last 30 years have seen several significant changes in these datums as better information has become available regarding the shape of our planet. Information taken from historical records regarding infrastructure to be modeled in conjunction with newly acquired data must include a consideration for conversion of both horizontal coordinates and vertical elevations to conform to the current datum.

## Summary

Derivation of contour linework from LiDAR derived bare earth mass points has been demonstrated to be an acceptable substitute for photogrammetrically derived contours. Utilizing a variety of techniques, a workproduct that is comparable, possibly more accurate, and equally useful as an overlay on photographic, planimetric, or in conjunction with other data has been demonstrated.

## About the Author

Larry Newman is the President of Spatial Systems Associates, Inc. (SSA), a GIS and FMIS implementation and support firm based in Columbia, Maryland. A graduate of the University of Maryland, Mr. Newman received his Masters degree in civil engineering in 1980. Mr. Newman is a registered professional engineer with over 20 years of civil engineering experience in the mid-Atlantic region prior to his establishing SSA in 1995. In addition, Mr. Newman is also a certified LEED AP.

SSA currently has a staff of approximately 14 professionals and support staff who provide comprehensive GIS and FMIS implementation and support services to federal, state, and local governments, as well as commercial businesses. SSA has been an Esri dealer, developer, and consultant since the firm was formed in 1995.