



HEXAGON

White Paper

Volumetric Measure Using Geospatial Technology

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Introduction

Using high-resolution terrain information generated from stereo imagery, you can obtain volumetric measurements for monitoring and surface analysis. In this whitepaper, we will detail workflows that could be used for such a task. We will prepare the project and stereo imagery, create a digital surface model (DSM), and take volumetric measurements.

For our demonstration, the goal is to collect volumetric measurements that show how much earth has been removed from a quarry or mine. However, this process could also be used for a variety of applications. For example, it could also be used to monitor geohazards, or estimate how many truckloads it will take to move landscaping or construction materials (such as gravel, sand, or dirt) that are stored in piles. You could also use it to measure the amount of debris deposited by a landslide, or the amount of glacial retreat that is occurring because of global warming.

During the demonstration, we will highlight sophisticated algorithms for generating and classifying dense elevation surfaces to allow for collection and analysis of information point clouds, as well as raster digital surface model (DSM) files from stereo imagery. This allows you to use stereo imagery you may already have, minimizing or eliminating the need to purchase LiDAR.

Project Setup/Triangulation

We begin by setting up a project to create a relationship between the raw images in a triangulated math model. This model is used to generate a high-density DSM using advanced pixel correlation methods (including semiglobal matching) on stereo image pairs from the results of the triangulation process.

These terrain extraction DSMs will be used as bare-earth DSMs that represent the ground surface both with and without the piles. We use spatial modeling technology to prepare the DSMs for the final steps of the calculations, which will be used to obtain the volumetric measurement of the pile. Finally, we can view the differenced DSMs in a 3D perspective viewer that can be filled with water to yield the volume of the inverted piles.

You can only run terrain extraction using imagery with proper project setup that has solved triangulation and enough overlap for stereo model creation. The triangulated result must be acceptable before you can extract terrain or perform feature extraction. To continue with the workflows described here, the project must be ready for terrain extraction and you will use two separate workflows with similar end products.

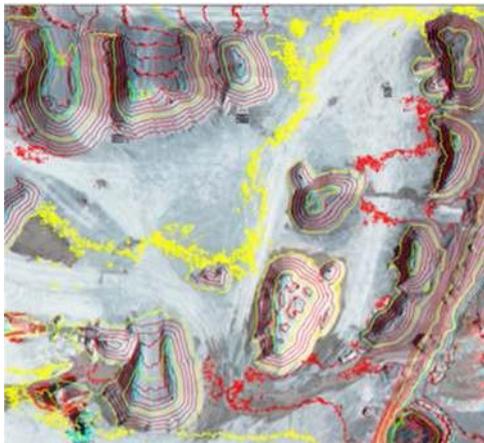
Additionally, you can seed the DSM extraction process by creating a mean terrain file. This is optional and basically gives you a breakline file to help in steep areas with little or no data and would help to provide a hard edge in such areas.

Workflow One: Extract DSM Terrain File

With a triangulated project, stereo models are used to generate surface files. This first workflow steps through the process of creating a raster DSM. Conversely, the second workflow steps through the creation of a point cloud dataset that will need to be merged into a raster DSM, so both workflows allow for volume calculations. The accuracy of your DSM output is directly influenced by the accuracy of your project/triangulation results. Make sure the setup parameters and options are suitable for your needs before running the extraction. Consider using seed sources like ground control points, and tie and breakline points from the accepted project triangulation to enhance the accuracy of the terrain extraction. The DSM created will be used to measure the volume of the spoil piles or quarry tailings for this project area. You can also use a second DSM for this volume calculation that is void of these piles and is an average or more generalized base surface elevation for the area. The second DSM would start merely as a copy of the original DSM extraction. The next steps will alter this second (copy) DSM file to create an average elevation around and including the area under the tailings/spoil piles. You are basically trying to create a true representation of the surface for these very specific areas, if one does not exist otherwise.

Stereo Terrain Editing

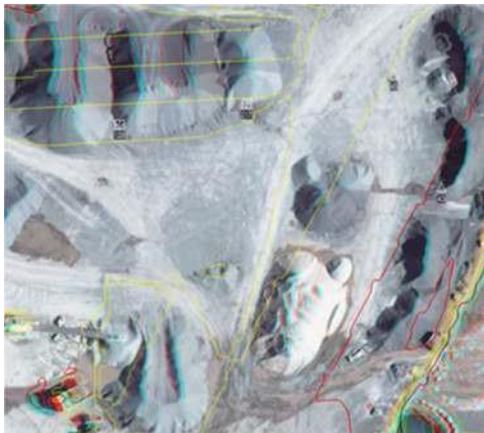
Using the **Fit Surface to Points Area** command, digitize a polygon around these spoil piles to create a planar surface. On-the-fly contour generation makes it easy to visualize changes to the post spacing (dynamically) with any changes made to the posts of this DSM. Viewing the DSM in a stereo environment makes it easier to edit and ensure your changes are at exact ground level. Simply remove the distortion (parallax) from the specific area for which you want to digitize a ground point, for each point along your polygon. Ensure that you are at the correct ground elevation for a point by removing the parallax for that specific distorted spot by adjusting the Z wheel. When you are sure that you are at the exact ground height, digitize that point and move to the next fit-to-surface point. Make this parallax adjustment for all spots surrounding the areas for which you want to create this average elevation surface, before digitizing another point for the fit-to-surface polygon. You can create this planar surface at a very local level around each pile, or at a more global level around all of the piles or features to be measured.



Dynamic contours showing the elevation features of the spoil piles

Fit Surface to Points

Using the Fit Surface to Points command creates a flat surface (as shown) by minimal contour relief. This will be differenced from the original to eventually extract the volume of the result. If you do not have before and after DSMs, you can interpolate the ground before spoil piles are created using the Fit Surface to Points tool. Both of these surfaces are considered bare earth (since no buildings, trees, or other features exist), hence the need to manually create an average surface of this area. It is necessary to digitize around the extremities of these spoil piles to interpolate the ground values in between. Digitizing around the entire study area instead of digitizing around individual piles may be a quicker way to create this averaged surface, but your interpolation may be too generalized. The Fit Surface to Points command creates a plane based on each digitized point for which you adjusted the Z value. Depending on the amount of slope or elevation difference in the study area, you may want to digitize more points to increase the accuracy of the results.



Contour plane showing how the surface has been averaged

Workflow Two: Extract Point Clouds

This workflow uses a point cloud as the starting elevation source. The point cloud could be an LAS file generated from a LiDAR sensor, or it could originate from a photogrammetry source. The point cloud will eventually need to be merged into a raster file to measure volume, because this procedure requires a gridded surface. The point cloud described in this workflow was derived using the semi-global matching algorithm. These software-derived point clouds have the advantage of being RGB-encoded and can contain more points than a LiDAR source for a precise DSM file. These point cloud files will be used to measure the volume of the spoil piles or quarry tailings for this project area.

Point Cloud Viewing and Editing

Point clouds are quickly becoming accepted as the most efficient and cost-effective way to generate accurate digital elevation and terrain data. In ERDAS IMAGINE®, you can display any point cloud in either a perspective or profile view for editing. In this workflow, we give the tailing piles a constant ground elevation, so we can difference them from the actual surface and calculate the volume. Make a copy of the original point cloud file for a constant surface generation. Using the profile tools, you can select points above the average ground elevation and drop them to the average surface for these specific areas. Keep in mind that you can consider the surface in terms of all of the piles being measured, or work on a more localized basis for a more discrete volume measurement.

Terrain Preparation

To collect volumetric measurements with these point clouds, you must first process them into a grid or continuous raster file surface. To accomplish this, merge all of the point cloud files (and any other TIN or raster files for that matter) into a single file. In this example, we will first merge point cloud files to create an IMG-formatted raster DSM file (containing all the tailings), and then we will merge files to create a second raster file that represents an average surface (for differencing). You could also simultaneously create a contour layer or classify your data to separate object types, as well as add projection information during this merging procedure.

Difference Modeling

To isolate the areas for which we want to gather volumetric measurements, perform an image differencing of the elevation files we have processed. If the dataset is ready for this measurement, you can simply take a DSM file and collect volume from it without these additional preprocessing steps.

For example, you could derive the volume of an entire open pit mine if you were not concerned about features inside it (like trucks) that would possibly influence the volume calculation. In this instance, we are concerned with more local features and isolating them requires some preprocessing.

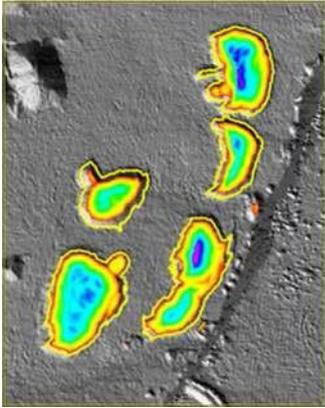
Using a spatial model, you can use the expression operator to subtract the original DSM from the newly edited DSM that has the spoil piles removed. This will provide a more accurate slope definition, as well as surface definition for each pile in question. Depending on what differencing method you use, it may be necessary to invert these piles if the differencing has not already done this. So, after you subtract the two elevation DSMs, you would include a multiplication by -1 in the spatial model subtraction operator. This creates an inverted DSM to be used for volumetric measure. In this case, we could have also used a surface difference tool to subtract DSMs, but you may still need to multiply by -1.

The use of this multiplication operation depends on whether the features you are trying to define are above the ground or already below the ground, and the order in which you perform the differencing. Because an open mine pit has some features that are already below a starting surface and some that are above the lower surface, it can get complicated very quickly. This situation illustrates why you would want to measure these features in a more localized fashion. In general, you can use the expression below to perform a DSM difference and invert the values, creating depressions that should provide the setup for most volumetric measurements:

$(\$Input1 - \$Input2)*(-1)$

Shaded Relief of Differenced DSMs

The difference of the DSMs has been colored to represent what will be measured or saved as a shapefile. This shapefile was created while simultaneously collecting the volumetric measurements in the next step. A color ramp was applied from a specific range of values to the spoil piles that are highlighted, and the surrounding areas are set to be transparent. Darker blues represent areas with more difference in elevation, soon to be filled with water for volume measure. The areas of difference are the only change you will notice, since we are differencing the same file except for the average surfacing we performed under the piles. These differences are delineated below.

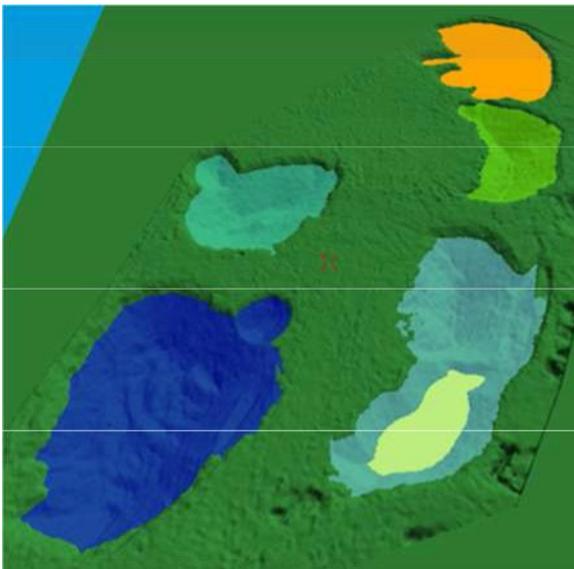


Use of a color ramp shows the elevation differences of the spoil piles atop of the shaded-relief DSM.

Volumetric Measure

Subtracting the DSMs shows local difference in the areas; in this case, it shows the spoil piles. The focus of this solution is simply to multiply any DSM by (-1) and fill in the depressions with water to yield a volume calculation. These spoil piles are filled with water in a 3D viewer using a flood tool. You can simultaneously obtain volume and surface-area measurements by clicking on the lowest spot and/or specifying how much of the depression you want to fill with water.

You can see the volume calculated by water fill in the 3D viewer. Multiple elevation levels can be collected at the same time for varying degrees of volume calculations. You can also difference these varied layers if you want. You can measure the entire area or specific smaller areas at once, depending on where your fill drop point is. The output is saved as a shapefile, which can also be used for surface area extents and measurement along with obvious overlay capabilities.



Volume measurements in a 3D viewer.



Orthorectification / Ortho Mosaic

In addition to collecting volumetric measurements of this study area, these DSMs created can also be used for orthorectification and mosaicking. You would run the terrain extraction first if the DSM is to be used for orthorectification or mosaicking. With proper project setup, you can use these DSMs as an input for your orthorectification engine instead of using a constant elevation. This will increase the accuracy and fit of your orthorectified imagery into a seamless mosaic, where applicable.

UAV/UAS and Other Applications

Mining companies are now employing Unmanned Aerial Vehicles (UAVs) and Unmanned Aerial Systems (UASs) for volumetric measure of tailings. Red cut lines indicate where smaller frames were mosaicked to create the image. These smaller areas are excellent candidates for UAV systems. The low-cost solution and quick turnaround time, coupled with a volumetric output, add value and information where resources were once scarce or too expensive.

Volumetric Measure

Volume measurements can be derived from any raster DSM, especially those that have some discernible features on them. In this particular workflow, we process the DSMs from stereo imagery, where perhaps LiDAR point clouds could be substituted. It is also possible to use an existing DSM and jump directly to the model to invert the DSM and volume measurements can begin with the model output. Additional processes were run in this example to show how to deal with other situations that can arise where a ready-to-measure DSM is not always the case. We took it a few steps further, and not only introduced the extraction of a DSM from imagery but showed how to isolate very specific regions within a DSM for more accurate volume calculations.

In this case, spoil piles or mining tailings were measured, but this same workflow could be used for other applications. The ability to measure the amount of avalanche or landslide debris covering a road could be invaluable to those trying to calculate how long it would take to remove the material. Knowing the volume of material in truckloads allows you to better estimate the time required for the project. Many workflows can utilize pre-existing image data. Depending on the resolution of the imagery, DSMs created from imagery are typically denser than those created from LIDAR. If you use the semi-global matching algorithm, you can get an extremely accurate elevation solution with hard edge results that are hard to beat. The applications for change detection seem endless and adding change in volume is no different.

These volumetric calculations are necessary to assign a dollar value to anything that takes up space and determine what it will cost to move the material.



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About Hexagon

Hexagon is a global leader in sensor, software and autonomous solutions. We are putting data to work to boost efficiency, productivity, and quality across industrial, manufacturing, infrastructure, safety, and mobility applications.

Our technologies are shaping urban and production ecosystems to become increasingly connected and autonomous — ensuring a scalable, sustainable future.

Hexagon's Geospatial division creates solutions that deliver a 5D smart digital reality with insight into what was, what is, what could be, what should be, and ultimately, what will be.

Hexagon (Nasdaq Stockholm: HEXA B) has approximately 20,000 employees in 50 countries and net sales of approximately 4.3bn USD. Learn more at [hexagon.com](https://www.hexagon.com) and follow us @HexagonAB.

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