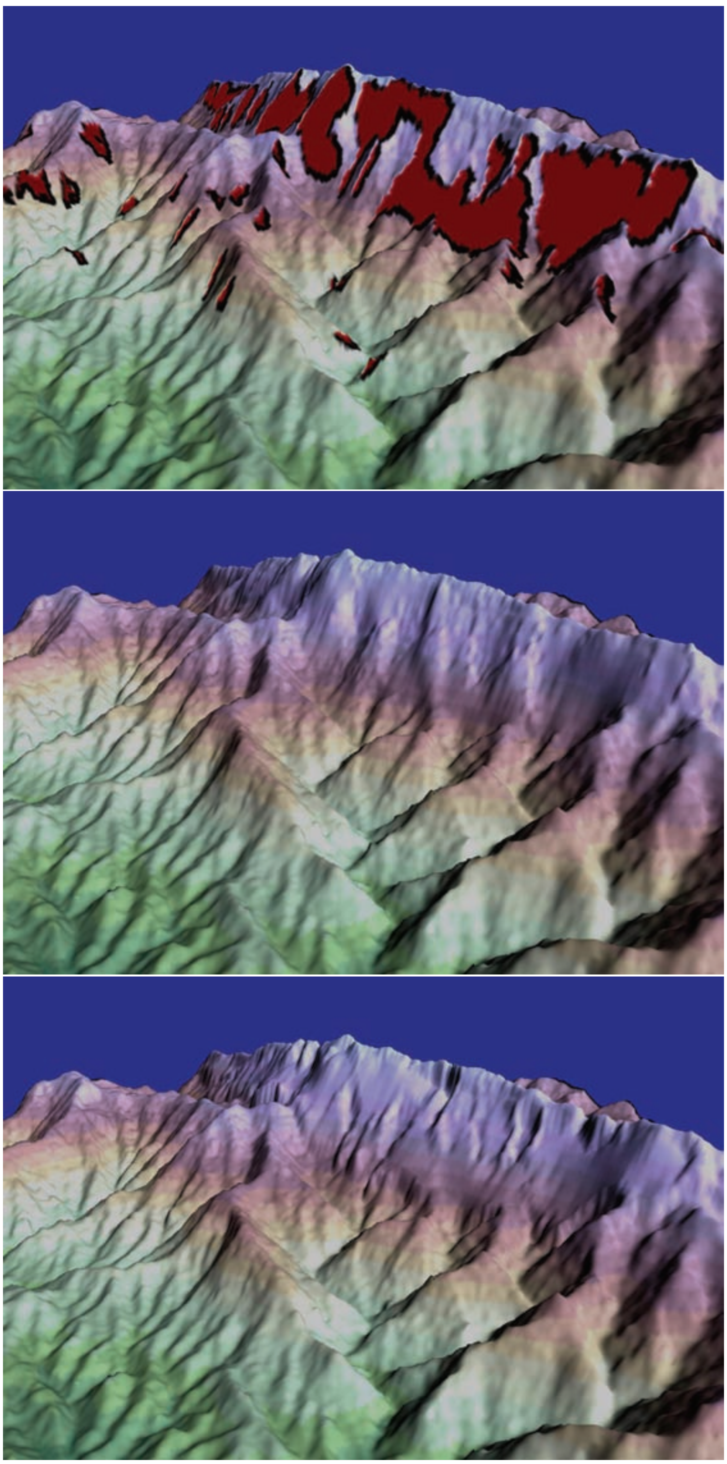
Filling SRTM Voids: The Delta Surface Fill Method

by Greg Grohman, George Kroenung, and John Strebeck



The top image portrays a perspective-view of a color-coded shaded relief portrayal of SRTM data with topographically-induced voids. The middle image shows the voids filled with the Delta Surface Fill methodology, and the bottom image shows the data filled with the Fill & Feather method.

In February 2000, the Space Shuttle Endeavour flew a single payload, 11-day mission (STS-99) in support of a joint project between the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA). The agencies designated this space flight as the Shuttle Radar Topography Mission, or SRTM. Prior to this mission, the only complete global digital topographic elevation data set was the United States Geological Survey (USGS) GTOPO 30 data, with one kilometer post spacing. The goal of this new joint project was to produce digital topographic data for 80% of the Earth's surface at a post spacing of one arc second (approximately 30 meters) (JPL Fact Sheet 400-713, 1998).

This SRTM data is quickly becoming a useful source of elevation data so critical to modern imagery analysis and geospatial intelligence (GEOINT) requirements. However, SRTM data has various sized holes, or voids, resulting in incomplete datasets. This causes many analysis processes (*e.g.* orthorectification, viewshed generation) to fail. Some of these voids can be attributed to the complex nature of IFSAR technology (Dowding *et al.*, 2004), while topographic shadowing can cause others.

A new technique to filling voids in SRTM digital elevation data is introduced here that shows improvement over traditional approaches, such as the Fill and Feather (F&F) method. In the F&F approach, a void is replaced with the most accurate digital elevation source (hereafter, "fill") available with the void-specific perimeter bias removed. Then the interface is feathered into the SRTM, smoothing the transition to mitigate any abrupt change. It works optimally when the two surfaces are very close together and separated by only a bias with minimal topographic variance. The Delta Surface Fill (DSF) process replaces the void with fill source posts that are adjusted to the SRTM values found at the void interface. This process causes the fill to more closely emulate the original SRTM surface while still retaining the useful data the fill contains. There is no need for feathering with the DSF approach.

The Fundamental Problem in Void Filling

If the SRTM and fill Digital Elevation Models (DEMs) differ by a vertical bias, the surfaces would seamlessly merge once this

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bias was removed. However, merely removing a bias, even a void-specific difference, from the fill will be insufficient if there are variable deltas and/or slope differences between the two surfaces (see Figure 1). Accordingly, the problem in void filling is interfacing the fill source DEM into the SRTM DEM in a seamless transition. This is difficult to achieve because of differences in DEM characteristics. Generally these occur due to the different means through which they are generated. Some factors impacting accuracy are DEM generation technology (lidar, radar, etc.), extraction specifications (reflected versus ground surface), horizontal accuracy (both internal variance and general bias), post spacing (possibly missing certain smaller features), and smoothing (often causing slopes to vary). DEM characteristics are also affected by the topography of the area being modeled, with more rugged areas often having less vertical accuracy. Each of these factors can cause the DEM to deviate with respect to the true ground or another DEM.

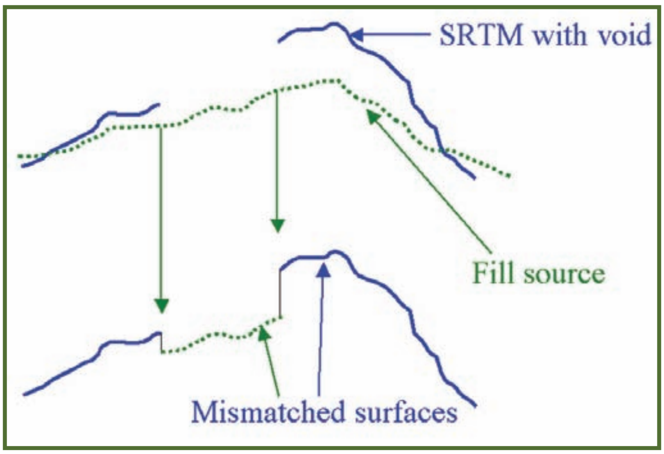

Figure 1.

The F&F process corrupts and smoothes the SRTM data near the void in an attempt to match the two surfaces over a small distance. This creates artificial slopes in the data that neither conform to the original surface nor represent the true ground. A more robust fill method should account for the DEM characteristic's variances.

The Delta Surface Fill Method (DSF)

The DSF method computes an adjustment of the fill source to the SRTM. For fill posts close to the void interface, there is a high probability, based on local trends, of successfully predicting the behavior of the two surfaces with respect to each other. As posts get further away from the known SRTM values and into the void, the confidence in the estimated adjustment to the fill source wanes. In large voids, at some point into the hole, the DSF will trend to removing only the vertical bias from the fill surface.

The Delta Surface Fill process:

1) Resample the fill surface to match the SRTM's post spacing.
2) Creation of the delta surface.
3) Populate center of large voids in delta surface with a mean value.
4) Interpolation across the voids in the delta surface.
5) Combine the interpolated delta with the fill source within the parent voids.

Resampling the Fill Source: The fill source must match the SRTM grid in its projection, datum, and post spacing. Fill sources of lower resolution than the SRTM are densified in this step. While there are numerous resampling techniques available, we found that Bilinear Interpolation returned the most favorable results for densifying elevation data.

Creation of the delta surface: The difference of the SRTM surface and the resampled fill source is computed. This returns a surface, termed here a "Delta Surface," that has voids coincident with the SRTM's voids (see Figure 2). Analysis of this Delta Surface may reveal certain qualities about the DEMs with respect to one another. As mentioned earlier, there are issues that leave telltale signatures in the Delta data. In addition, the Delta Surface review may highlight radar-related problems in SRTM data (Honikel, 1998; Honikel, 1999). If problem areas are detected, the SRTM is edited and the Delta Surface regenerated.

Placement of the mean plane: The center area of a large void in the

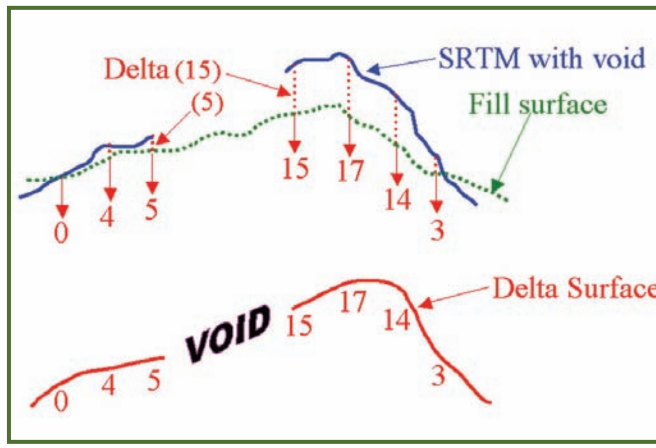

Figure 2.

Delta Surface is assigned a constant value equal to the mean value of the overall difference between the SRTM and fill (*i.e.* the bias). Testing has suggested a 20- to 30-pixel distance into the SRTM voids for the location at which to begin the mean plane. This step is the vehicle by which the statistical mean difference is removed from the fill data, allowing it to be placed on its own inside large voids of the SRTM.

Interpolation across the voids in the Delta Surface: The remaining void posts in the Delta Surface (smaller voids and those areas between the void edge and the mean plane) are filled with an interpolated value. We used an inverse distance weighted interpolation algorithm (Clarke, 1995; Davis, 1986). A refinement in this algorithm implemented in the DSF consists of a series of targeted smoothing filters. Reviews of SRTM data show that the data near voids could be noisy as the signal strength weakened in these areas during collection. Therefore, a small filter in the initial few posts into the interpolated values is used to slightly dampen this effect.

Combine the interpolated delta with the fill source: The interpolated Delta Surface is the vehicle by which the fill source posts are adjusted to seamlessly transition from the original SRTM data. Each newly interpolated post value in the Delta Surface is combined through addition with its corresponding fill post and placed inside the SRTM void. Once completed, the entire SRTM surface will have all its voids seamlessly filled (see Figure 3).

Comparison to Fill and Feather

Testing was performed on artificially induced voids of variable sizes in SRTM data within one-degree cells. Voids were manually created in areas that were topographically similar to areas in SRTM that are prone to voids. For these tests, the one-degree cells had varying relief types while the fill sources had varying quality.

Visual inspections: Plate 1 displays the results of an SRTM void being filled with a poor quality DTED® in a color contour view. The images at the top show an SRTM2 dataset (1 arc second posts, or approximately 30 meters) on the left with a circle showing an artificial void, while on the right the same area is depicted in the DTED®1 (3 arc seconds posts). The image series on the bottom shows the solutions that the DSF and the F&F processes generated with the original SRTM2 in the middle. The DSF solution appears more like the original surface than F&F.

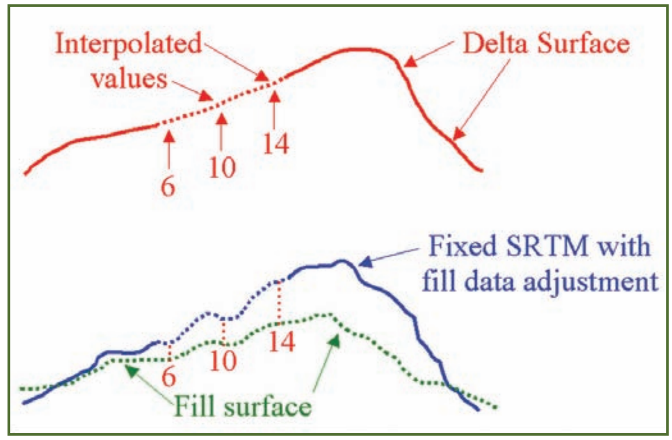

Figure 3.

Process performance can also be reviewed by generating an "error surface" found by differencing each of the solutions with the original SRTM "ground truth." In Plate 2, the error surface is colored tan where the fill solutions match the SRTM. Several differences between the two processes are revealed. Most obvious is that the non-zero error values cover a larger area in the F&F results (left) than the DSF results (right). This is due to F&F's degradation of the SRTM in the feather regions *outside* the void (Kuuskivi *et al.*, 2005). Further analysis shows a frequently occurring trend. Near the void edges, areas of poor transition are visible in the F&F example (see areas A, B, C, and D). The corresponding locations in the DSF show a much smoother transition (see areas E, F, G, and H).

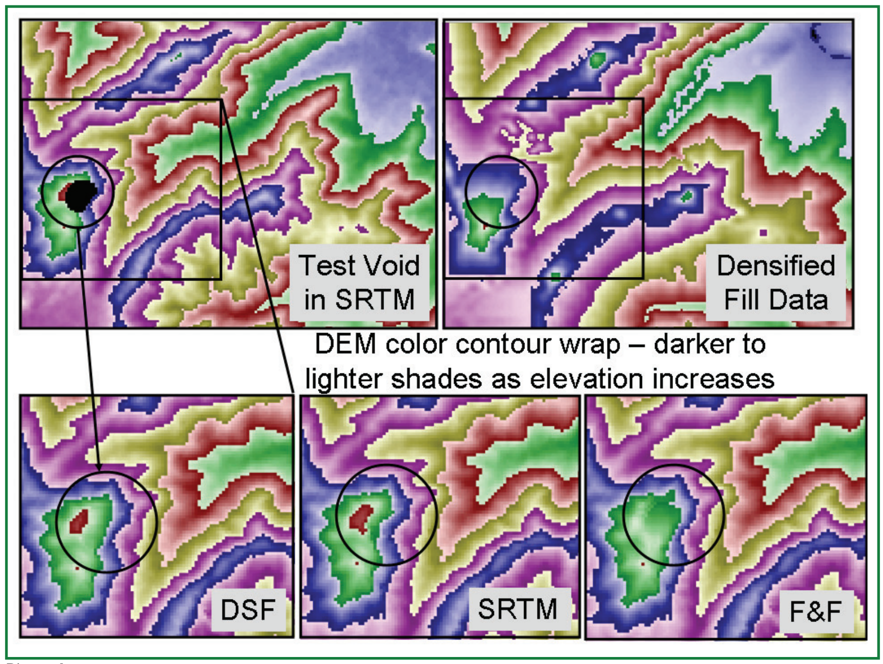

Plate 1.

The error surface can also be visualized in a 3D perspective-view color-enhanced wire mesh as seen in Plate 3. It shows the same data set found in Plate 2, but from a southeast perspective and with a slight vertical exaggeration. This view gives a different perspective of how poor F&F performed at some edges. Also visible is the problem area caused by poor fill data that impacted both the DSF and F&F solutions.

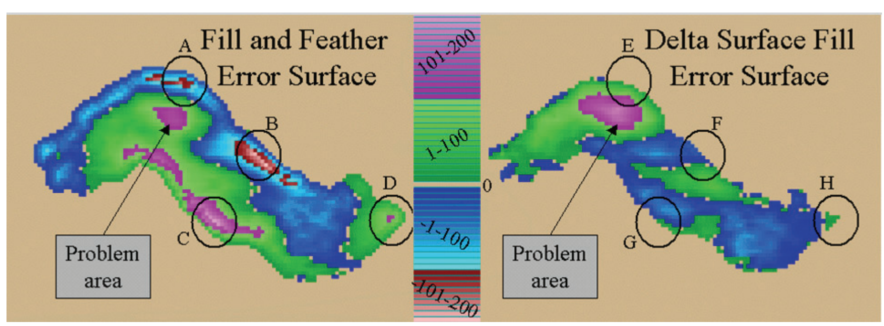

Plate 2.

Test Cell Statistics Table 1 lists SRTM and fill source characteristics on the left. The "Relief" column indicates the topographic variance of each cell. The "Fill Look" column is a subjective rating, reflecting judgment of visual aspects of the fill source, such as feature representation, smoothness, level of detail and editing artifacts. The "Fill AV" column is the Absolute Vertical (AV) Accuracy (LE90) of the fill source generated by computing errors at precise ground control points (GCPs).

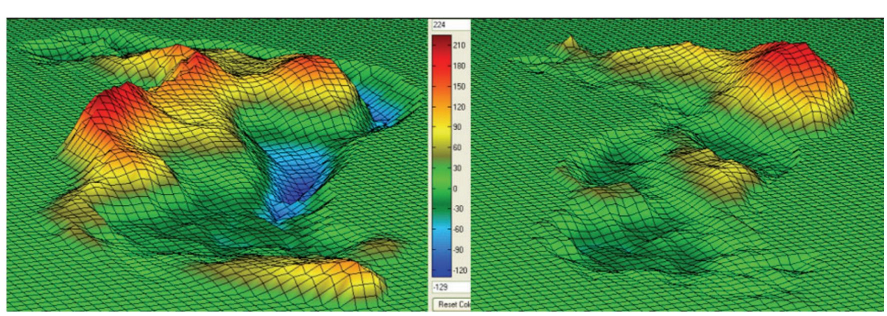
Plate 3.

In order to compare the DSF and F&F,

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Table 1.

Cell	Number of Voids	Relief	Fill Look	Fill AV	F&F avg SD	DSF avg SD	% SD Reduced
1	3	Rugged	Fair	51.29	57.69	47.11	18.36
2	2	Moderate	Poor	60.73	53.29	20.42	61.68
3	3	Moderate	Good	9.57	17.91	16.03	10.51
4	2	Flat	Fair	13.19	8.61	4.71	45.22
5	2	Moderate	Poor	35.61	49.87	29.13	41.59

statistics were generated comparing each solution to the original SRTM data, or "ground truth". For each induced void, the Standard Deviation (SD) of the error surface is computed. These statistics are averaged for the two processes within each test cell and compared. A lower SD indicates that the associated fill solution better conforms to the original SRTM. The final column lists the percentage of improvement in the average SD of the DSF over the F&F. The results show that across the board, DSF is a statistical improvement over F&F results.

Summary

This article presents a new technique for filling voids in SRTM DEM data. Tests prove the increased effectiveness of DSF in filling SRTM voids compared to the F&F technique, especially at the problematic void interfaces. DSF gives better results by both visual and quantitative measures. Because of these performance improvements, DSF is now in use by NGA and its contractors in SRTM void filling. In addition to operations on SRTM datasets, DSF has application to other DEM-level void filling endeavors. Numerous combinations of elevation data can be used in the parent and fill surface roles.

References

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