AN EFFECTIVE FILTER FOR REMOVAL OF PRODUCTION ARTIFACTS IN U.S. GEOLOGICAL SURVEY 7.5-MINUTE DIGITAL ELEVATION MODELS*

Michael J. Oimoen
Raytheon ITSS / USGS EROS Data Center
Sioux Falls, South Dakota USA

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ABSTRACT

Many digital elevation models (DEM) produced by the U.S. Geological Survey suffer from the presence of striping artifacts, which limit their utility. The most common approaches to filtering the affected DEMs rely on simple low-pass filters that blur fine details. A new filtering algorithm has been developed that isolates the stripes by applying a low-pass filter along the axis of the striping, followed by high-pass filtering orthogonal to the stripes. Once isolated, the artifacts are subtracted from the DEM to yield clean, detailed terrain data.

1. INTRODUCTION

Over half of the U.S. Geological Survey 7.5-minute digital elevation models currently in the National Digital Cartographic Data Base (NDCDB) were created using one of two photogrammetric methods: manual profiling and electronic image correlation. In both cases, the resultant DEM's contain production artifacts that affect their accuracy, and interfere with the accuracy of derived products, such as slope, aspect, and hydrology.

This paper presents, in its simplest form, a filtering algorithm that has proven effective in the suppression of most common production artifacts, and which has found application in the creation of the U.S. Geological Survey's National Elevation Dataset.

2. DESCRIPTION OF DATA

2.1 MANUAL PROFILING

The manual profiling technique of DEM generation used an analytical stereoplotter fitted with a three-axis coordinate digitizer. With a human operator controlling the height of the measuring mark, successive profiles were scanned at fixed intervals in a back-and-forth motion across the stereo model (Grout, 1994; Brunson and Olsen, 1978).

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Unfortunately, the data thus collected reflect " …a systematic operator tendency to profile above ground while scanning downhill and underground while scanning uphill" (Brunson and Olsen, 1978). In combination with the alternating scan directions, these small bias errors result in a DEM marred by the presence of horizontal stripes. The Rockypoint, Wyoming, 7.5-minute DEM (fig. 1a) is typical of such data. It was produced in 1980 at the USGS Rocky Mountain Mapping Center with a Wild A-7 analytical stereoplotter.

2.2 ELECTRONIC IMAGE CORRELATION

Many 7.5-minute DEM's were compiled using the Gestalt Photomapper II (GPM II). An electronic correlator within the unit determined elevations by measuring the parallaxes of numerous points within 9- by 8-mm areas of the diapositives. After a 9- by 8-mm patch had been processed, the diapositives were physically shifted to a new location, and the process was repeated (Brunson and Olsen, 1978; Kelly et. Al., 1978).

DEM's produced by this technique exhibit a visible, rectangular pattern caused by slight discontinuities between adjacent correlation patches. The Adon NW, Wyoming, 7.5-minute DEM (fig. 1b), produced in 1979, is typical. The cause of this artifact is not entirely clear, but it may have arisen from minute pointing errors encountered as the diapositive stages were shifted.

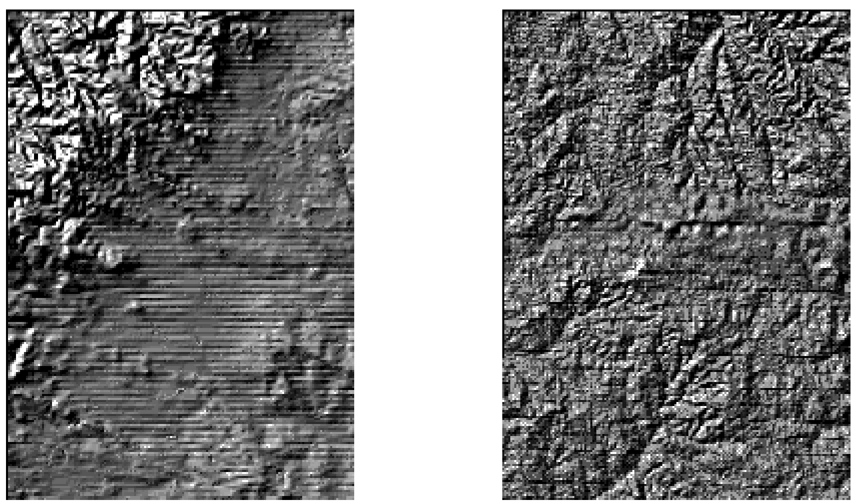


Figure 1a (left) Shaded relief. Rockypoint, Wyoming 7.5-minute DEM
1b (right) Shaded relief. Adon NW, Wyoming 7.5-minute DEM

3.0 COMMON FILTERING STRATEGIES

Considering the ubiquitous nature of these production artifacts, surprisingly little is to be found in professional literature concerning either their nature or their remediation. Most published methods for filtering DEM's concern either random noise or isolated gross errors, rather than systematic production artifacts, and they typically use simple loss-pass filters. For example, Hassan (1988) considers the low-pass filtering of white noise from individual elevation profiles, and Vieux (1993) low-pass filtered a 7.5-minute DEM by convolution in an attempt to reduce the impact of spurious pits before delineating watersheds. Similarly, Kok et al (1987) suggest a two-dimensional Wiener low-pass filter for the restoration of DEMs produced by the GPM II. The two-fold assumption in each case is that terrain is adequately represented without high-frequency components and that noise and artifacts are largely high-frequency phenomena.

Even specific attempts to suppress the banding present in manually profiled DEM's often rely on low-pass filters. Brown and Bara (1994) investigated the use of unweighted convolution kernels ranging in size from 2 by 2 to 3 by 7 (with the longer dimension perpendicular to the stripes), and Garbrecht and Starks (1995) considered kernels of 5 by 5 and 1 by 5.

Although a willingness to discard high spatial frequencies may be justified in the presence of broad spectrum uncorrelated noise, it is likely to be ill-founded elsewhere. There is a visible loss of information in DEM's that have been filtered in this way (fig. 2).

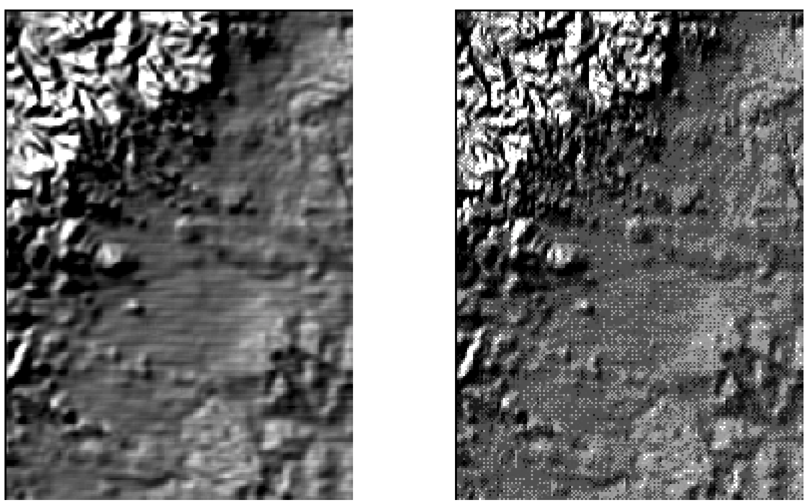


Figure 2a (left) Shaded relief of Rockypoint, WY DEM low-pass filtered by Convolution with an unweighted 7 x 7 kernel.

Figure 2b (right) Shaded relief of Rockypoint, WY DEM low-pass filtered by Convolution with an unweighted 1 x 7 kernel (vertically oriented).

A more conservative approach by Pan (1989) deals with the periodic nature of the stripes present in the manually profiled DEM's, suppressing them to a considerable degree in the Fourier domain by using a simple point mask.

Recent experiments have led to a filtering scheme, the mean profile filter, that is effective in attenuating artifacts while retaining the DEM's full complement of spatial frequencies.

4.0 THE MEAN PROFILE FILTER

4.1 SPECTRAL AND SPATIAL CHARACTERISTICS OF STRIPING ARTIFACTS

Production artifacts created by the GPM II and by manual profiling processes have a distinct spectral and geometric character that simple low-pass filters, and even frequency notch filters, only partially address. Manual profiling stripes, for instance, are visibly a high-frequency phenomena, and low-pass filters thus enjoy some measure of success in eliminating them. These stripes are also low-frequency features, evidenced by their persistence across the entire width of the DEM and explained by their origin as bias errors. This latter property is exploited to create an improved filter that can more readily distinguish artifact from terrain.

4.2 THE MEAN PROFILE ALGORITHM

Consider an elevation profile defined by a single column taken through the North-South axis of a striped DEM (fig. 3a). Although the presence of bias errors is evident, the profile also contains valid high frequency terrain information that would be lost were a low-pass filter applied. The proposed solution is to average a number of neighboring columns to obtain a mean profile – a result that may be easily obtained by separately low-pass filtering each row of the DEM. Since the biases that form the stripes are roughly constant over a fairly wide interval, the striping pattern persists while high-frequency terrain features are strongly attenuated (fig. 3b). A mean profile thus reveals high spatial frequencies which may be attributed exclusively to the unwanted artifacts.

High-pass filtering each column separates the artifacts from the remaining low-frequency terrain features, resulting in a raster consisting entirely of the striping artifact (fig. 3c). Simply subtracting the isolated artifacts from the original DEM completes the process (fig. 3d).

In summary, then, the mean profile filter consists of the following steps:

Step 1: Low-pass filter the DEM along the axis of the stripes.
Step 2: High-pass filter the result from Step 1 at a right angle to the striping.
Step 3: Subtract the result of Step 2 from the original DEM.

To obtain the best results, the low pass filter should use the lowest cutoff frequency that does not begin to attenuate the stripes themselves. The high-pass filter should use the highest cutoff frequency which captures the striping intact.

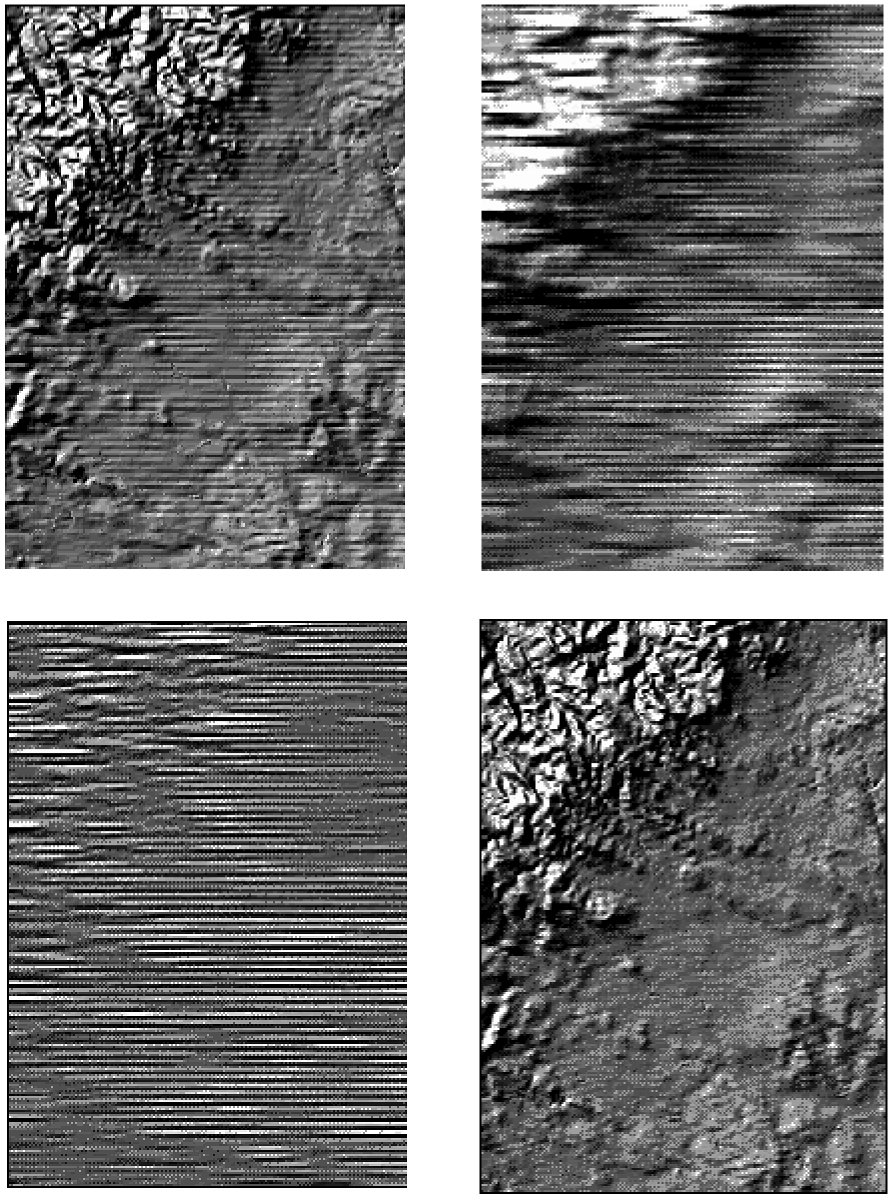
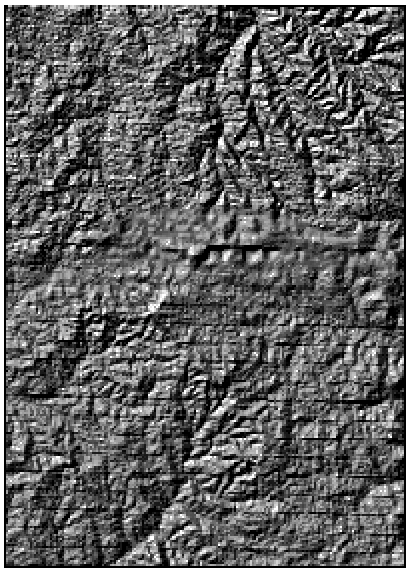


Figure 3a (upper left) Rockypoint, WY DEM, unfiltered.
Figure 3b (upper right) 3a low-pass filtered with 31 x 1 unweighted kernel (horiz)
Figure 3c (lower left) 3b high-pass filtered with 1 x 9 unweighted kernel (vertical)
Figure 3d (lower right) Subtract 3c from 3a, yielding improved data.

The stripes that form quilted patterns in DEM's produced by the GPM II may also be isolated and removed using mean profiles (fig. 4), although the stripes present in these DEM's differ in some respects from the bias striping in manually profiled DEM's. To remove the usually less pronounced vertical stripes from such a DEM requires a second filtering in which mean profiles are constructed by averaging rows.



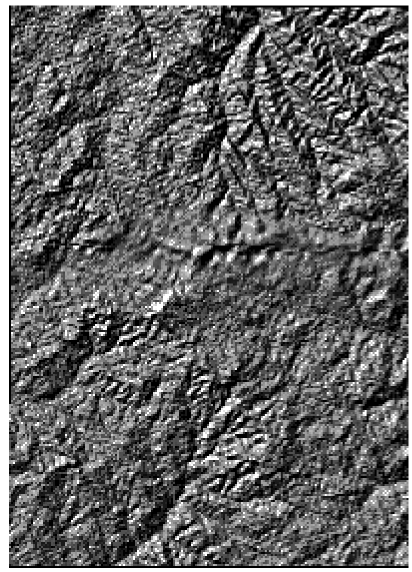


Figure 4a (left) Adon NW, Wyoming DEM before filtering
Figure 4b (right) after two passes of mean profile filtering

5.0 RESULTS OF FILTERING ON DERIVED PRODUCTS

The mean profile filter's effectiveness is perhaps best illustrated by the improved quality of derived products, since many DEM-dependent applications rely more heavily on elevation derivatives than they do on raw elevation.

Slope, for example, is a common derived product, and is particularly sensitive to relative errors. A comparison of slope images derived before and after filtering confirms the mean profile filter's effectiveness in suppressing artifacts while retaining fine detail (fig. 5).

Additional confirmation is provided by a comparison of derived hydrology. Manual profile striping, while small in amplitude, is nonetheless sufficient to significantly distort drainage patterns (fig. 6a). Drainage lines derived from the filtered DEM (fig. 6b) not only present a more natural appearance but agree well with features delineated on corresponding maps.

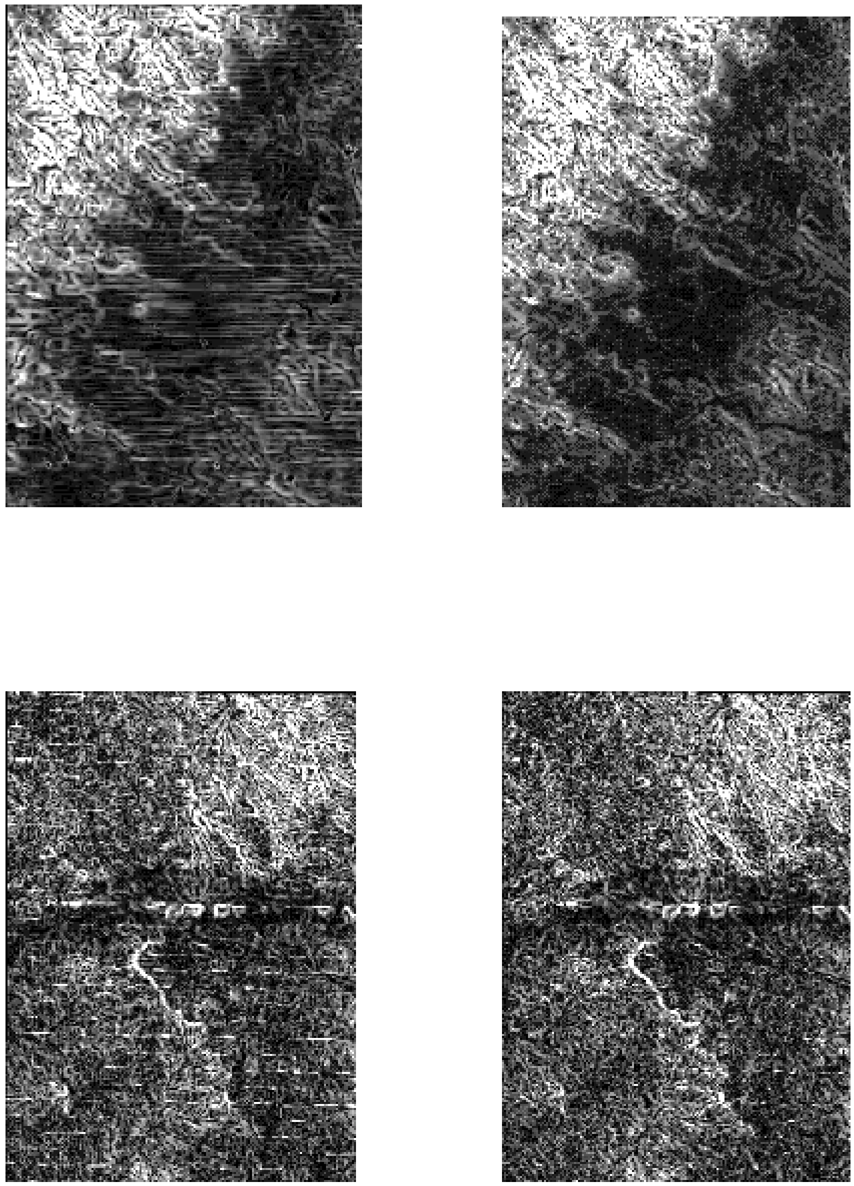


Figure 5a (upper left) Slope image. Rockypoint, WY DEM prior to filtering
5b (upper right) Slope image. Rockypoint, WY DEM after filtering
5c (lower left) Slope image. Adon NW, WY DEM prior to filtering
5d (lower right) Slope image. Adon NW, WY DEM after filtering

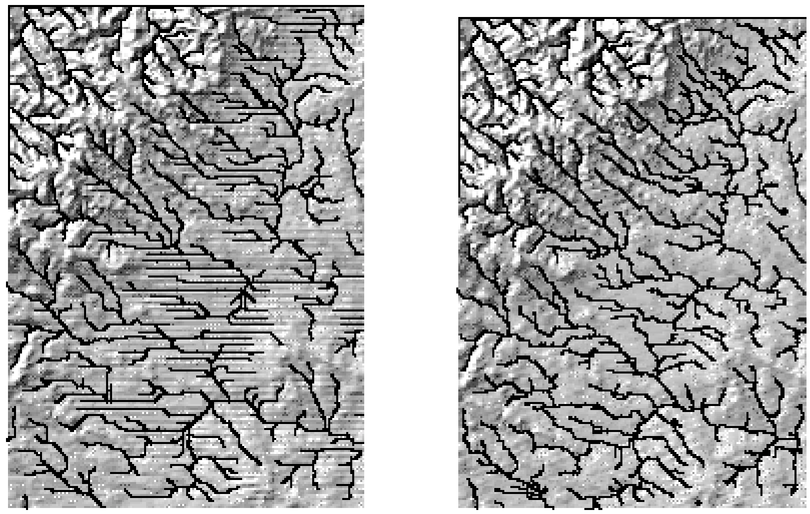


Figure 6a Synthetic drainage derived from striped DEM
6b Synthetic drainage derived from destriped DEM

6.0 CONCLUDING REMARKS

Experiments with the mean profile filter on a variety of photogrammetrically generated DEM's have shown it to be effective over a broad range of striping artifacts. Test filtering high quality DEM's produced by non-photogrammetric methods further reveals that the mean profile technique has very little negative effect on valid terrain features.

Potential refinements to the process include the use of skewed filtering kernels to better match the orientation of stripes that do not fall precisely along rows or columns.

7.0 REFERENCES

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